Something in the Air: Infectious Aerosols from COVID-19 to Measles and Our Tools to Fight Them

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Dalla Lana School of Public Health

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Disclosures

Work presented includes slides used with permission from Profs. Kim Prather, Lidia Morawska, Giorgio Buonnano, and Linsey Marr.

Work presented here was funded in part by the Institute for Population and Public Health at Canadian Institutes for Health Research and by the National Institute for Allergy and Infectious Diseases at the US National Institutes of Health.

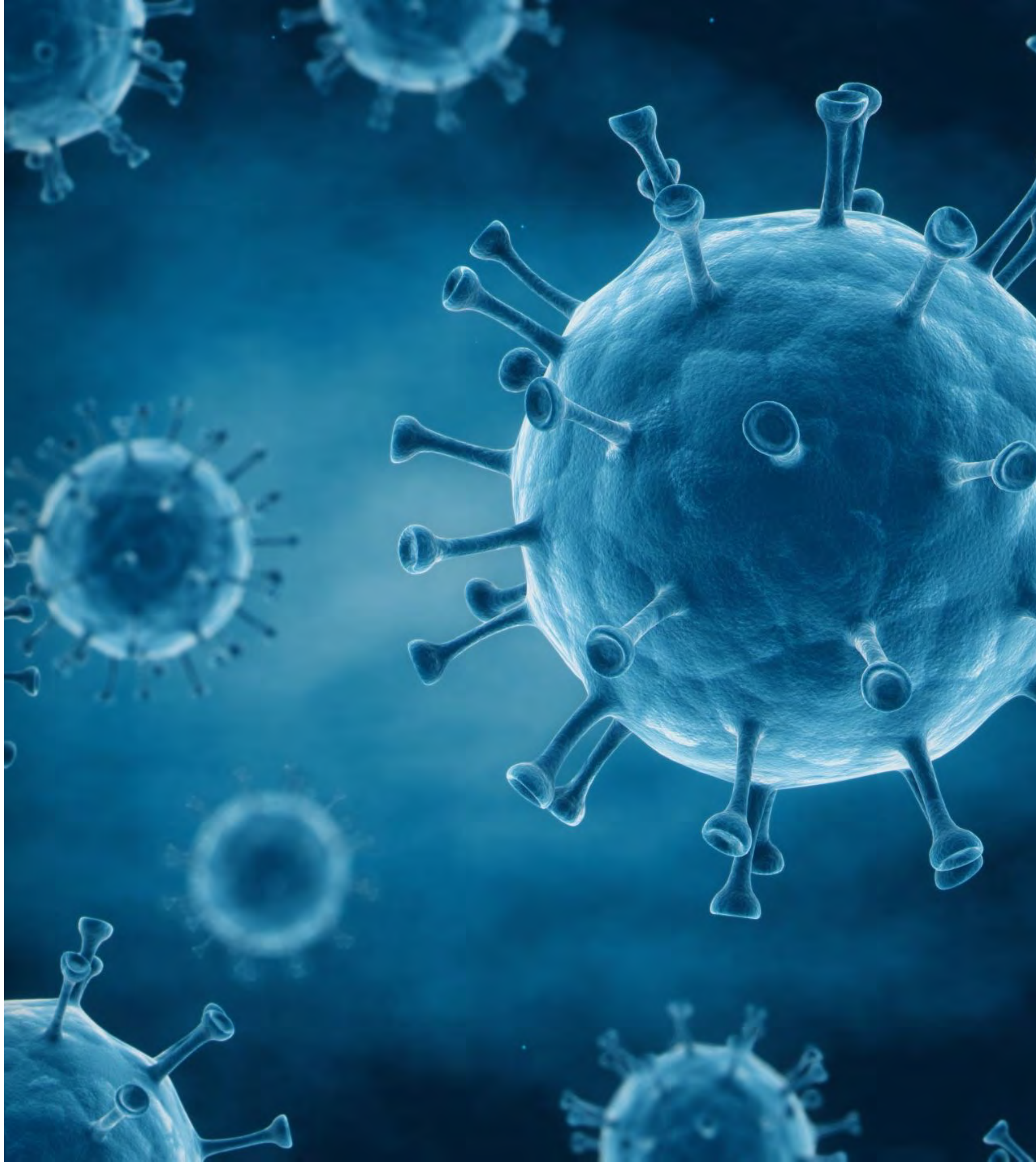
I have served on advisory boards for a number of vaccine companies, including Pfizer, Merck, Sequirus, Sanofi-Pasteur and AstraZeneca. I have provided epidemiology short courses to Pfizer employees and have served as a consultant on RSV vaccine modeling to Moderna.

I have served as a paid legal expert for the Ontario Nurses' Association, Elementary Teachers' Federation of Ontario and as a *pro bono* expert for EcoJustice.

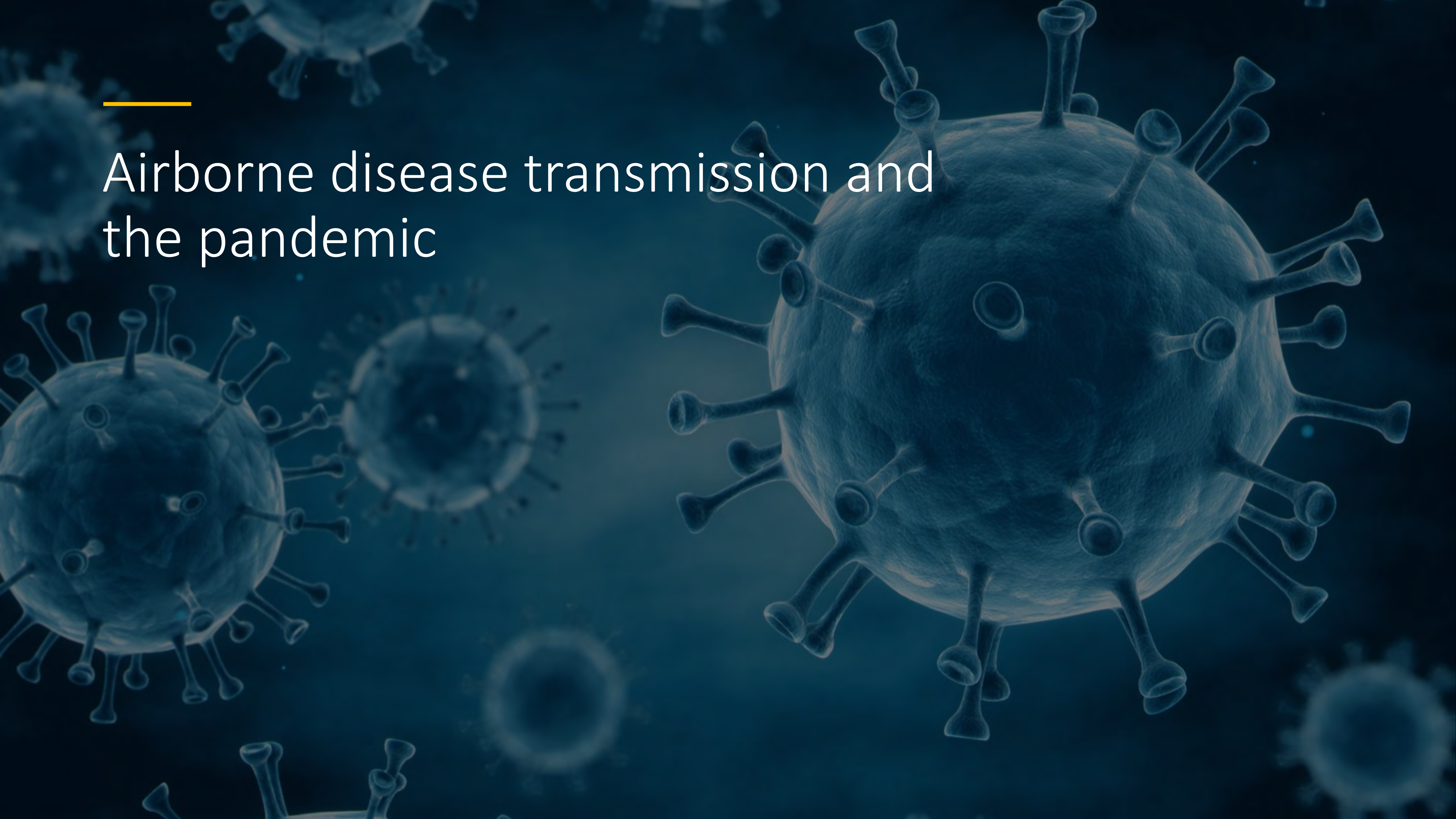
I have provided paid consulting on COVID-19 to JP Morgan-Chase and Farallon Capital.

Outline

1. Airborne disease transmission and the pandemic
2. Introduction to infective aerosols
3. Historical origins, present day messaging
4. Tools for control
    1. Indoor air as a surveillance resource
5. Other health benefits of clean indoor air
6. The return of measles and simple models of herd immunity

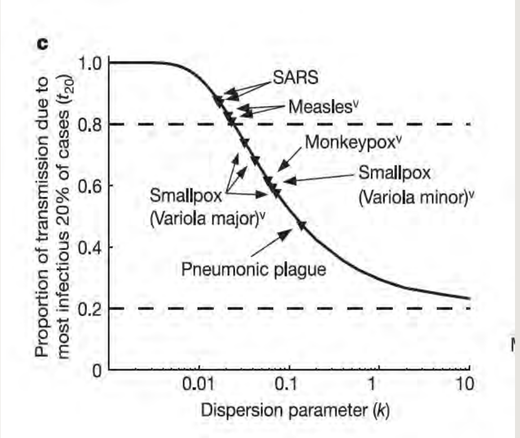


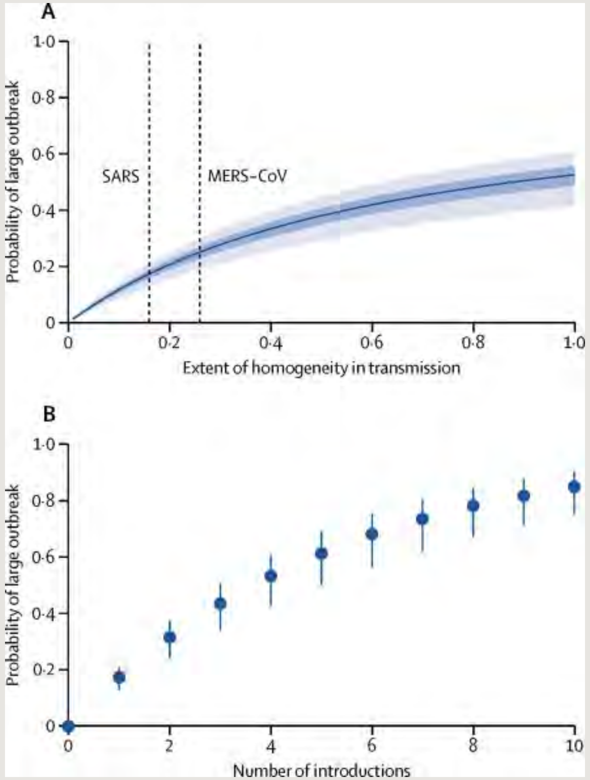
Airborne disease transmission and the pandemic

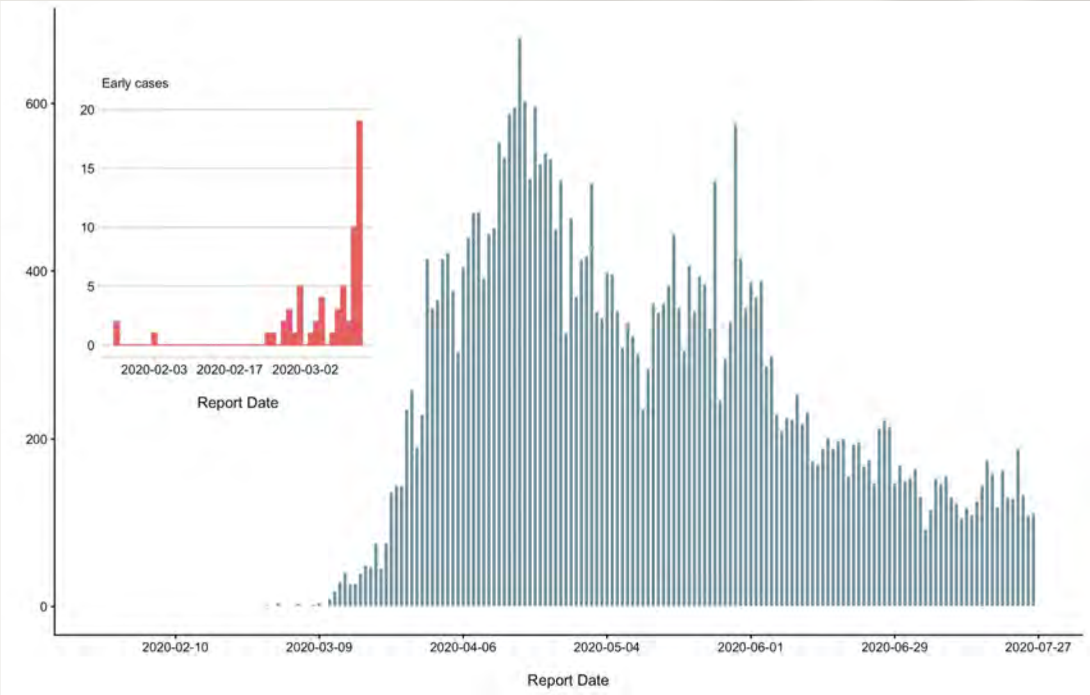


The SARS-CoV-2 Pandemic

Overdispersion: R_0 described by negative binomial distribution where mean = R_0 and variance = $R_0(1+R_0/k)$ (k is a shape parameter).



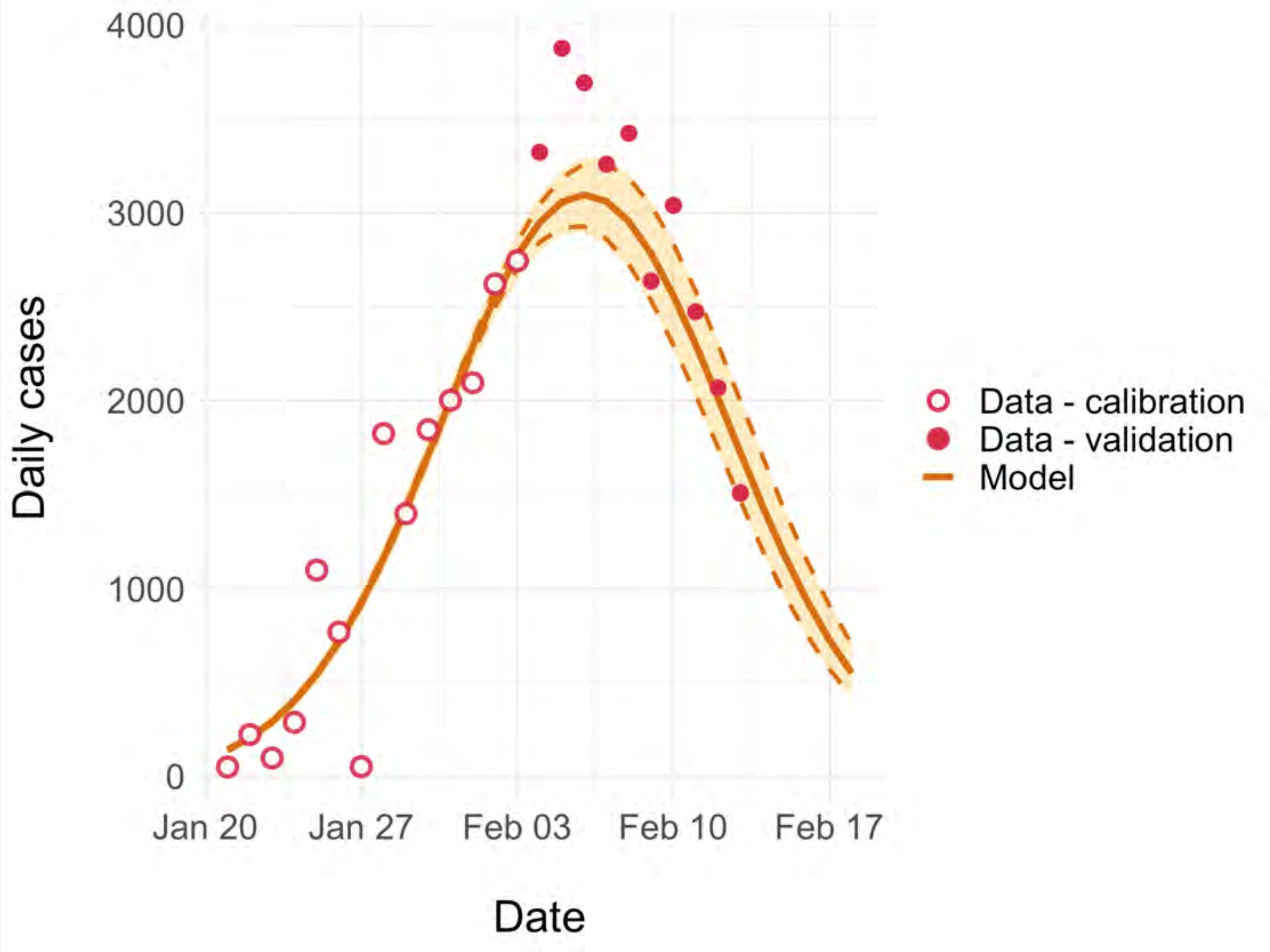




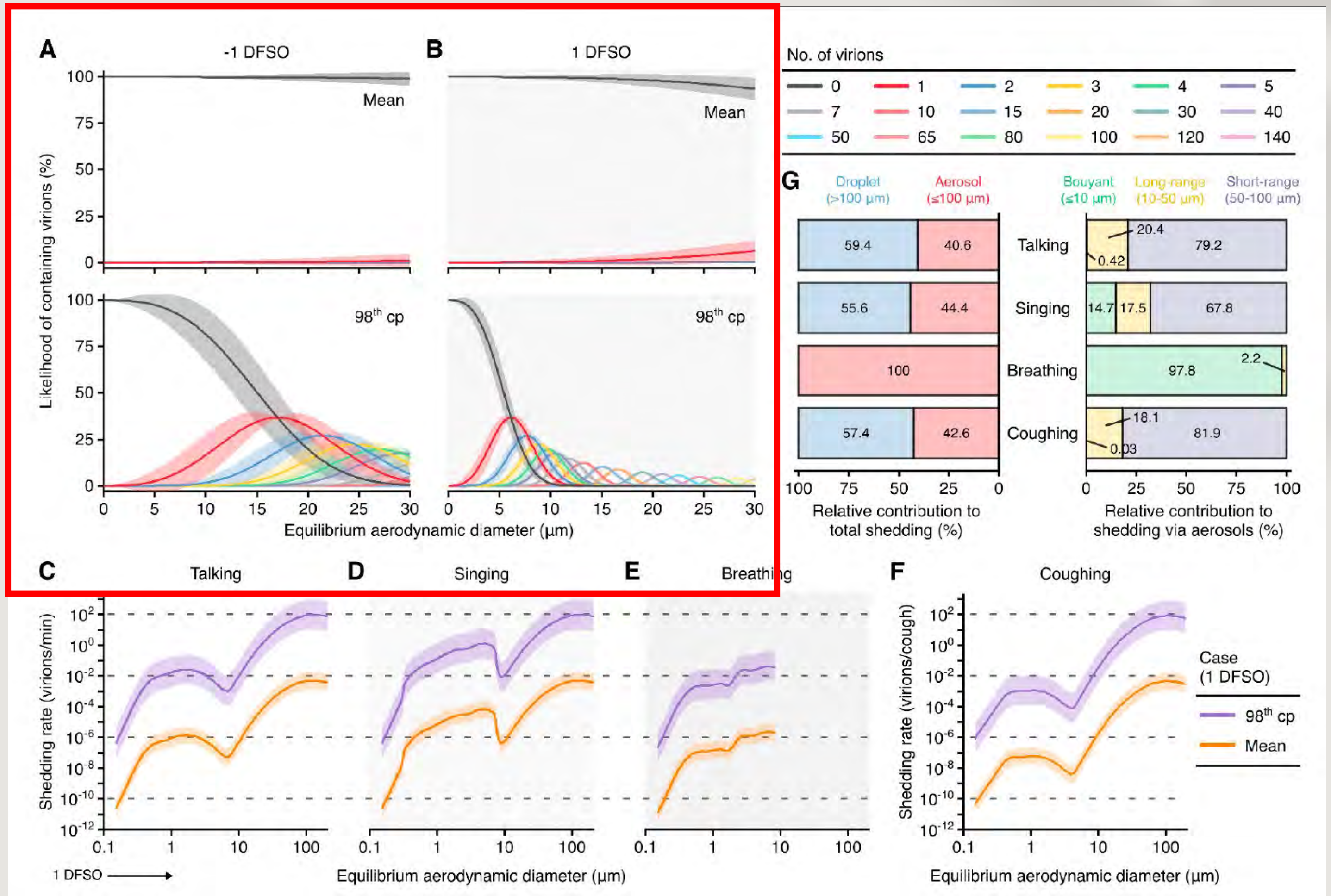
OVERDISPERSION: SINGLE INTRODUCTION USUALLY RESULTS IN NO EPIDEMIC (DEAD ENDS)

(Lloyd-Smith et al., 2005, https://www.ncbi.nlm.nih.gov/pmc/articles/pmid/16292310/, Kucharski et al., 2020 https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30144-4/fulltext)

SARS-CoV-2 Emergence Had Overdispersed R_0 and Was Controllable

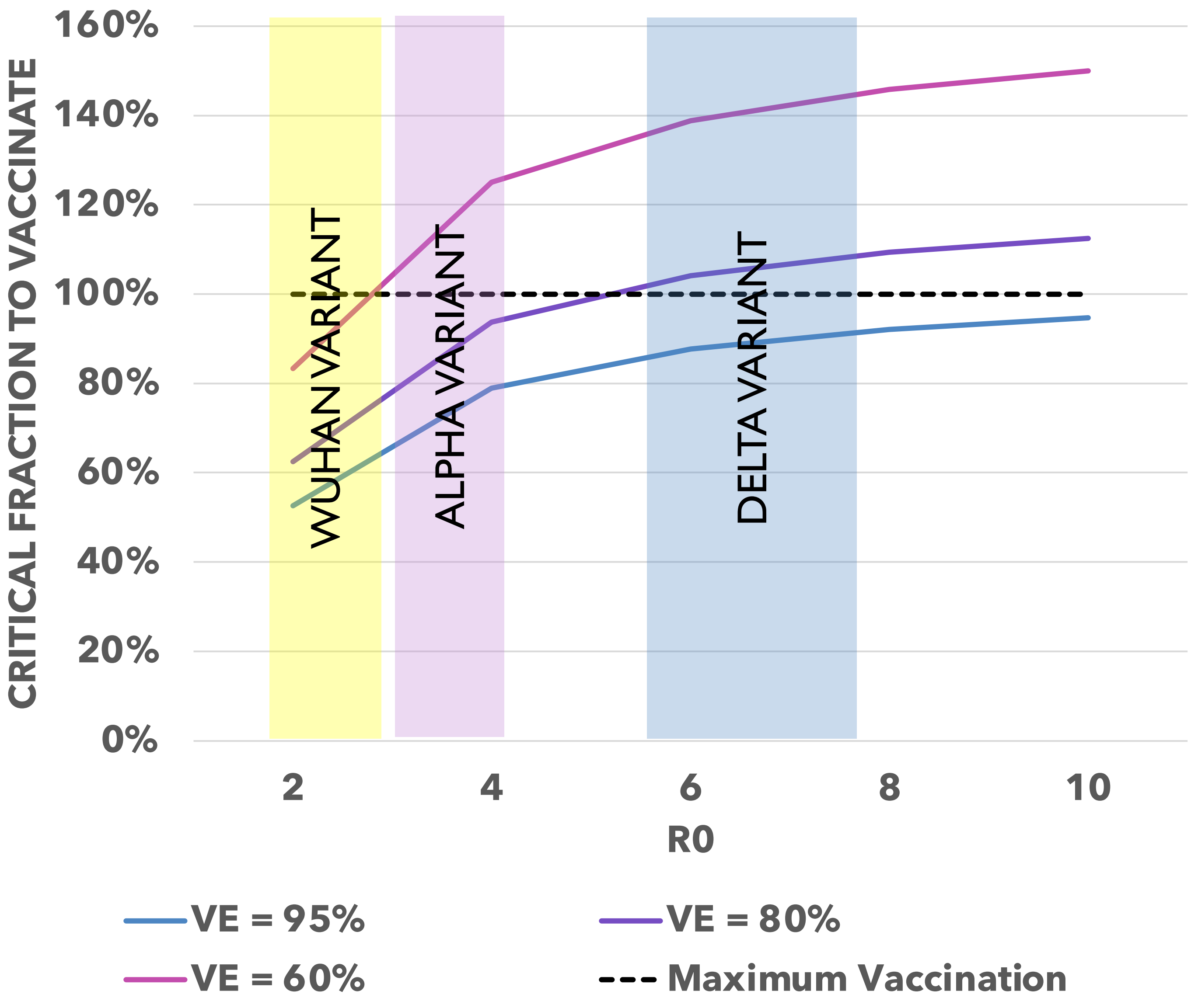


Mechanistic Basis of Overdispersion?

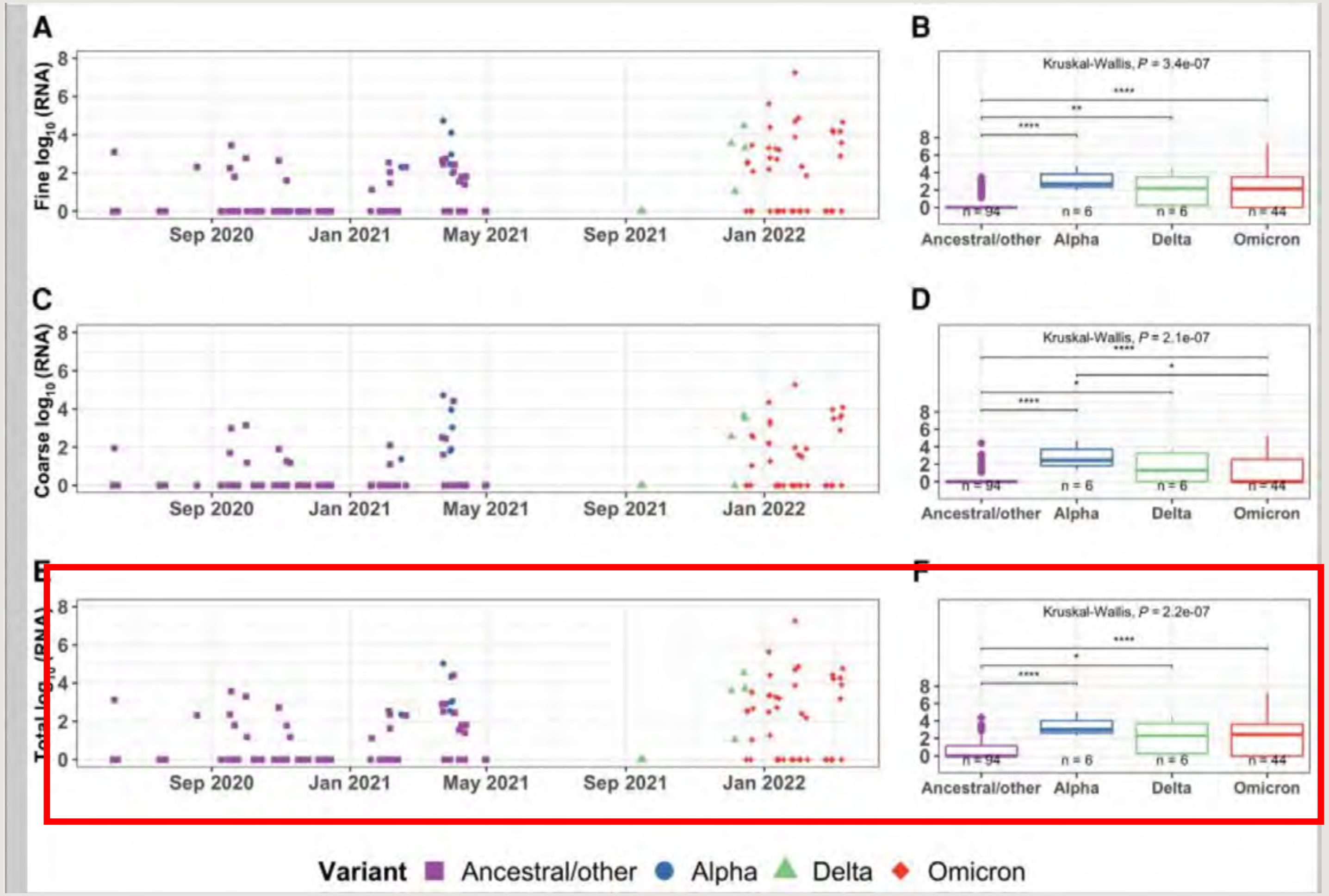


Source: Paul Chen et al., https://doi.org/10.7554/eLife.65774

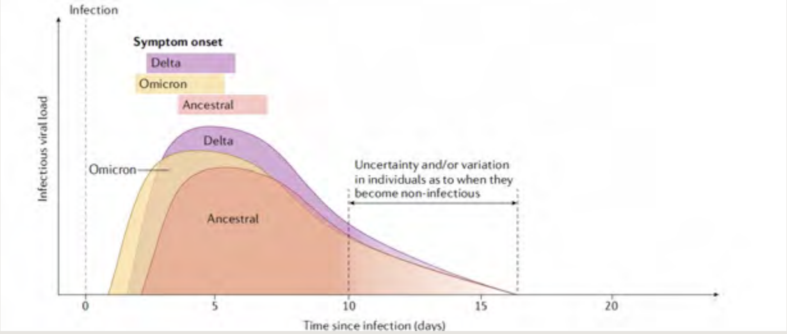
Implications for herd immunity



Rising R_0 Over the Course of the Pandemic: Partially A Function of Wells-Riley "Quanta"?



Increased R_0 also affected by changing viral kinetics over the course of infection (Puhach et al. 2023, https://doi.org/10.1038/s41579-022-00822-w)

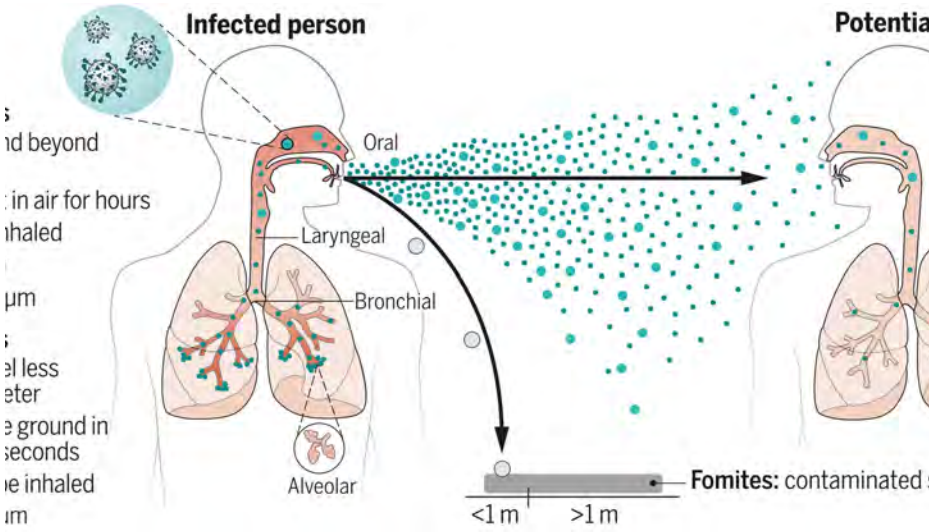


Lai J, Coleman KK, Tai SHS, German J, Hong F, Albert B, Esparza Y, Srikakulapu AK, Schanz M, Maldonado IS, Oertel M, Fadul N, Gold TL, Weston S, Mullins K, McPhaul KM, Frieman M, Milton DK. Exhaled Breath Aerosol Shedding of Highly Transmissible Versus Prior Severe Acute Respiratory Syndrome Coronavirus 2 Variants. Clin Infect Dis. 2023 Mar 4;76(5):786-794. doi: 10.1093/cid/ciac846

Introduction to infective aerosols

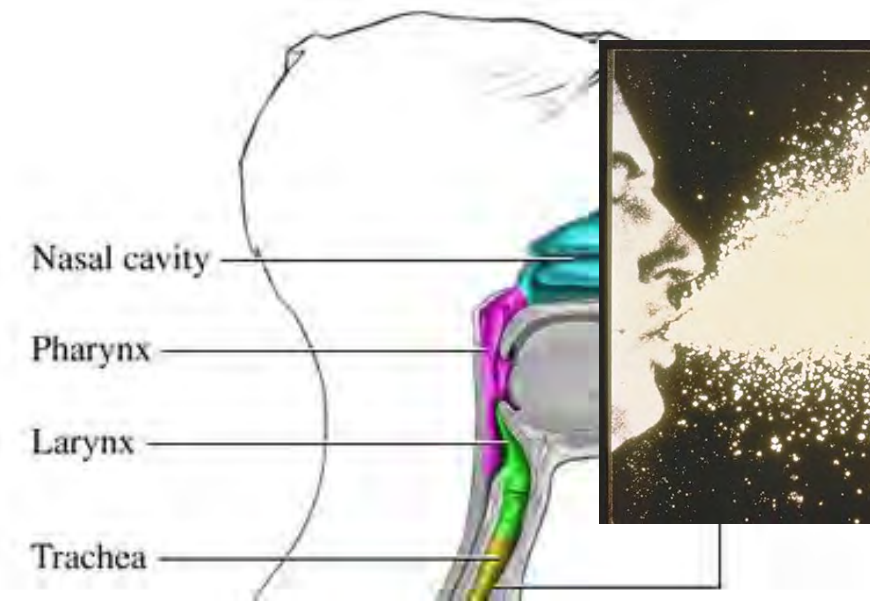
Airborne transmission of infection

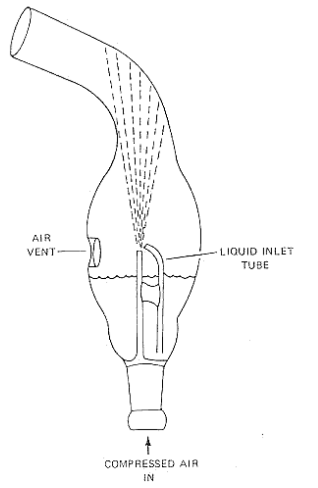
- Aerosols: a suspension of small particles in air.
- Exhibit "buoyancy": do not fall to the ground based due to pull of gravity as expected with larger particles.
- Size threshold for aerosol behavior in respiratory aerosols is around 100 μm diameter.
- Infection via inhalation.



Source: Wang CC et al., 2021. https://www.science.org/doi/10.1126/science.abd9149

Particle aerosolization in respiratory activities





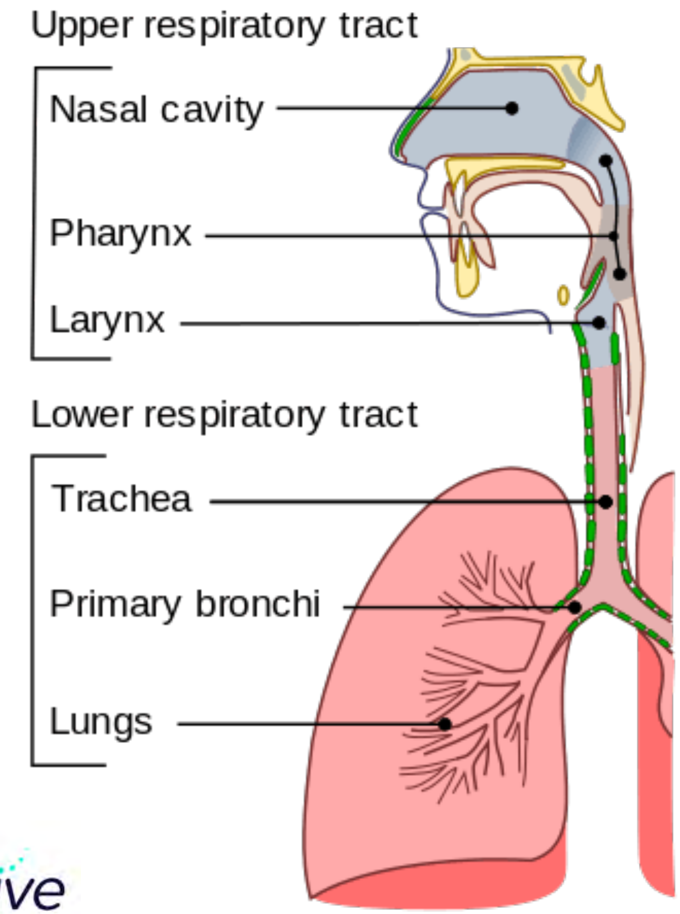
….results from the passage of an air-stream at a sufficiently high speed over the surface of a liquid

Thrive

QUT

Slide courtesy of Professor Lidia Morawska

Generation of respiratory particles



Saliva in the **mouth** is aerosolised during interaction of the tongue, teeth palate and lips during speech articulation

Fluid bathing the larynx is aerosolised during voicing due to vocal fold vibrations

Fluid blockages form in respiratory **bronchioles** during exhalation

They burst during subsequent inhalation produce the particles

After formation, the particles undergo processes in the respiratory tract before they are emitted

Deposition – changing initial size distribution

Surface deformation (Oratis et al. 2020 A new wrinkle on liquid sheets: *Turning the mechanism of viscous bubble collapse upside down*. *Science*, 369(6504): 685-688, 2020

Viruses and bacteria in the particles?

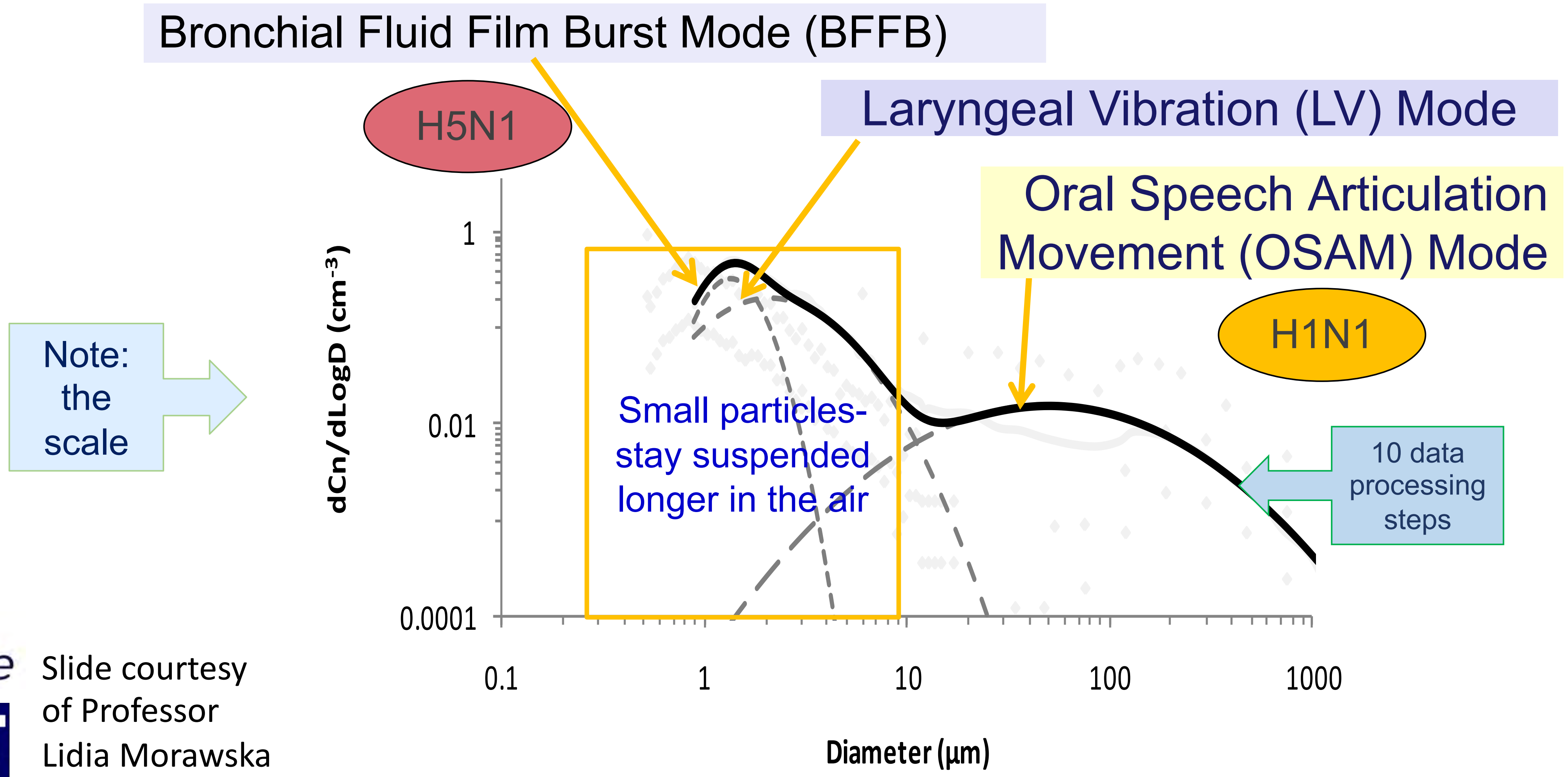
Thrive

QUT

Slide courtesy of Professor Lidia Morawska

Johnson, G.R. and Morawska, L. The Mechanism of Breath Aerosol Formation. Journal of Aerosol Medicine and Pulmonary Drug Delivery, 22: 229-237, 2009.

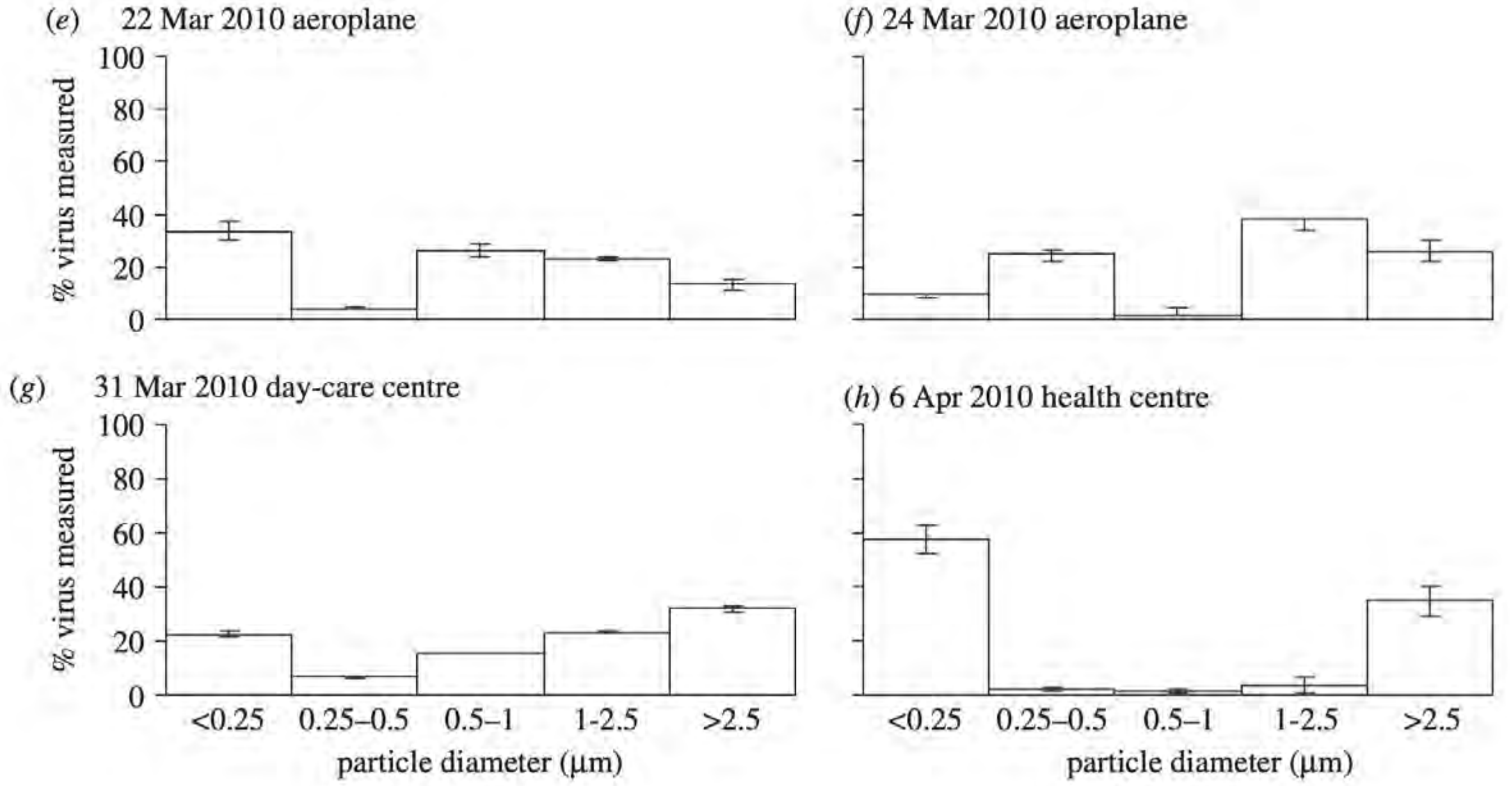
Number size distribution: speech + breathing



Slide courtesy of Professor Lidia Morawska

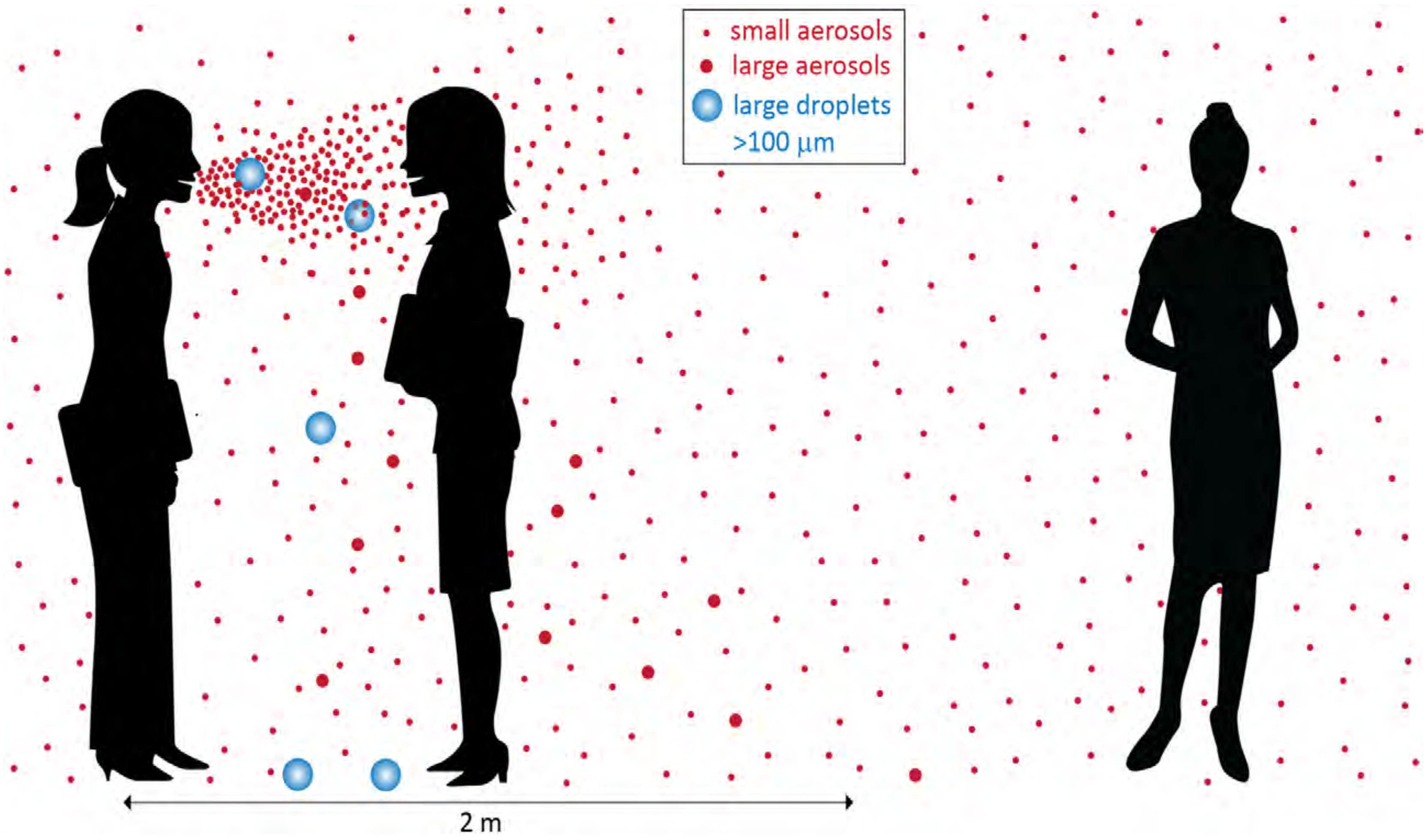
Morawska et al., Size distribution and sites of origin of droplets expelled during expiratory activities. *Journal of Aerosol Science*, 40: 256-269, 2009

Respiratory Viruses (and TB) Concentrate in Small, Buoyant Particles

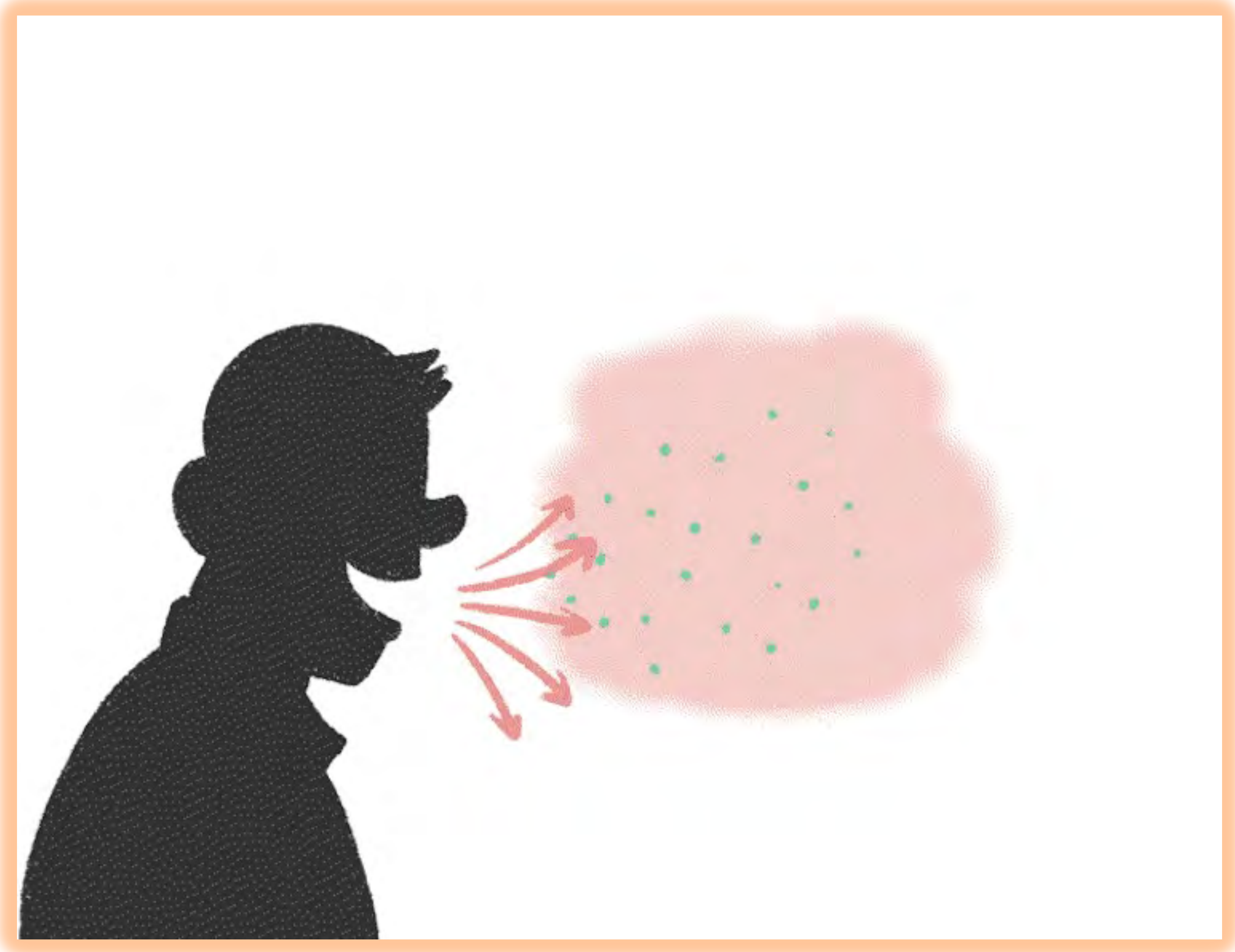


Yang et al., 2011. https://royalsocietypublishing.org/doi/10.1098/rsif.2010.0686.

What were the historical reasons for the resistance to recognizing airborne transmission during the COVID-19 pandemic?



Indoor Air, Volume: 32, Issue: 8, First published: 21 August 2022, DOI: (10.1111/ina.13070)



Slide courtesy Professor Lidia Morawska.

Morawska, L. Australia must get serious about airborne infection transmission. Here's what we need to do. *The Conversation,* 26 July 2021.

MYTH

1) Aerosols are smaller than 5 µm
2) Everything larger than 5 µm falls within 1-2 m
3) If it's short range, then it can't be airborne
4) Aerosols only matter for aerosol generating procedures

FACT

1) Aerosols can be up to 100 µm in size
2) A 5 µm particle can travel hundreds of meters
3) Short-range transmission is dominated by aerosols
4) Talking and coughing are aerosol generating procedures

(1) Tang, J.W., Bahnfleth, W., Bluyssen, P., et al., 2021, Dismantling myths on the airborne transmission of severe acute respiratory syndrome coronavirus (SARS-CoV-2), *J Hosp Inf* (2) Prather, K.A., Marr, L.C., Schooley, R.T., et al., 2020, Airborne transmission of SARS-CoV-2, *Science*

“Aerosol Generating Procedures” Don’t Generate Much Aerosol. But Talking Does.

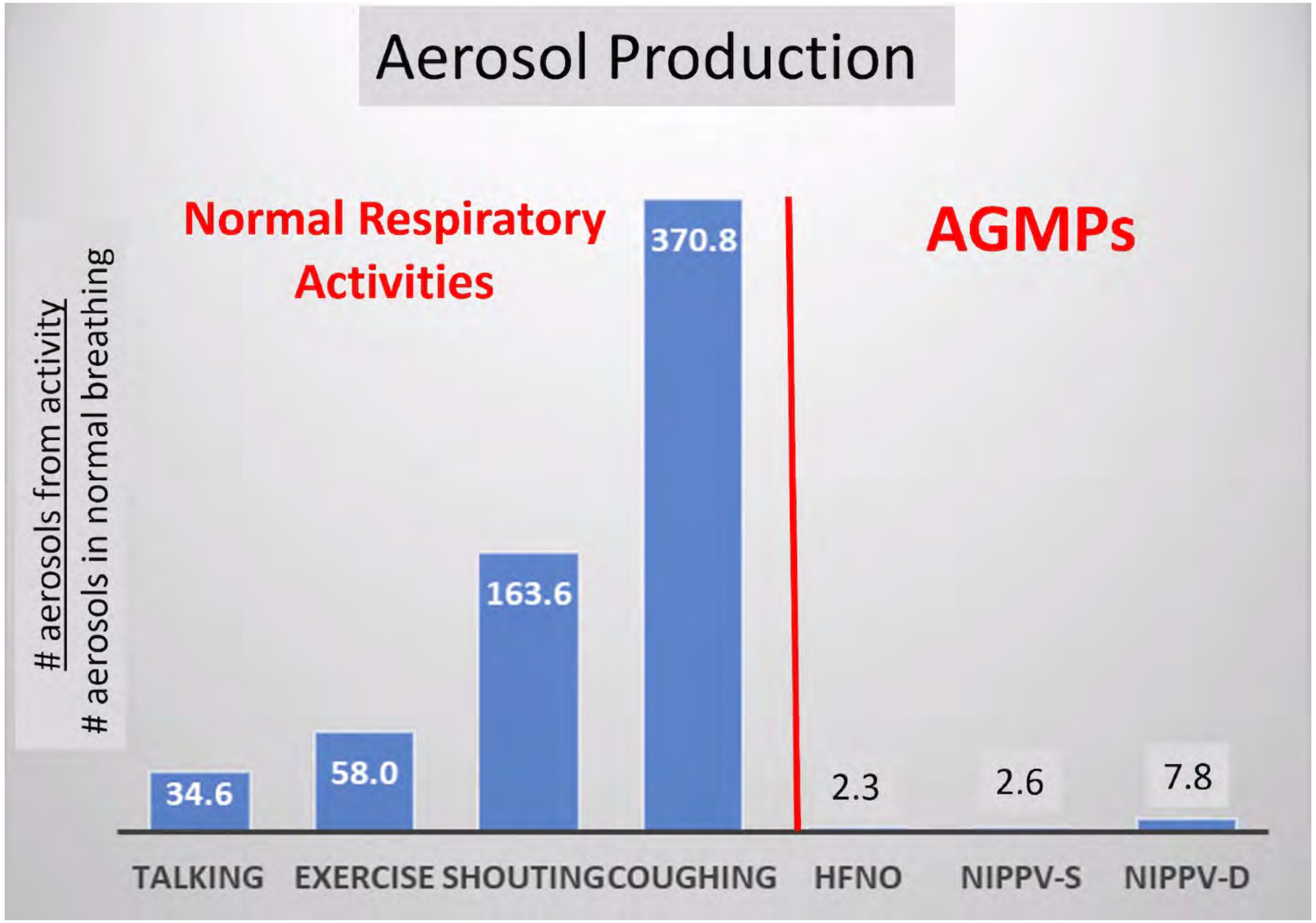


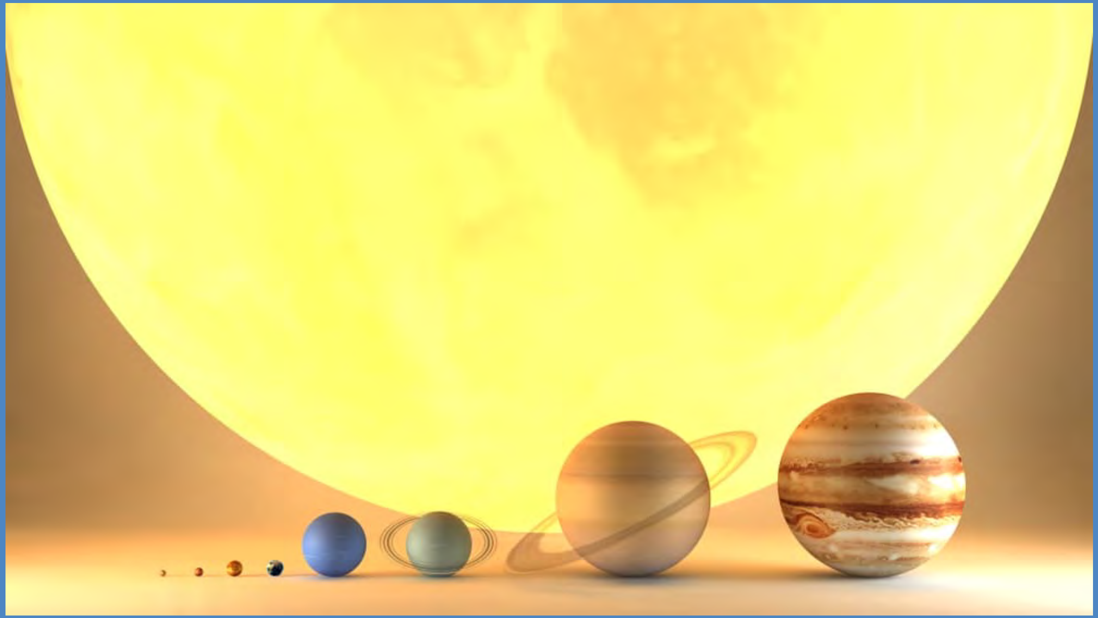
Figure courtesy Dr. Kim Prather, adapted from Wilson et al., 2021.

Other respiratory viruses likely transmitted via airborne spread

Table 1. Airborne transmission of respiratory viruses. Representative evidence of airborne transmission for various respiratory viruses and their basic reproduction number. Cells with dashes indicate not applicable.

Virus name	Scope of studies and/or approaches							Basic reproduction number (R_0)
	Air sampling and PCR	Air sampling and cell culture	Animal models	Laboratory or clinical studies	Epidemiological analysis	Simulation and modeling	Size-resolved information	
SARS-CoV	(31)	(31)	–	(30)	(30)	(30)	–	2.0–3.0 (197)
MERS-CoV	(32)	(32, 103)	(103, 198)	(32)	–	–	–	0.50–0.92 (197)
SARS-CoV-2	(41–44)	(34, 35, 40)	(33, 37, 199)	(34, 45, 107)	(36, 64, 71, 72, 186)	(36, 50)	(34, 41, 43)	1.4–8.9 (57, 58)
Influenza virus	(22, 23, 98, 102, 106)	(23, 98, 101)	(24, 137, 200, 201)	(24, 138, 202, 203)	(20)	(20, 114, 204)	(23, 105, 106)	1.0–21 (205)
Rhinovirus	(9, 27)	(26, 28)	–	(26–28)	–	(27)	(9)	1.2–2.7 (205)
Measles virus	(16)	(16)	–	–	(17)	(17)	(16)	12–18 (206)
Respiratory syncytial virus (RSV)	(102)	(25)	–	(25)	–	–	(25)	0.9–21.9 (205)

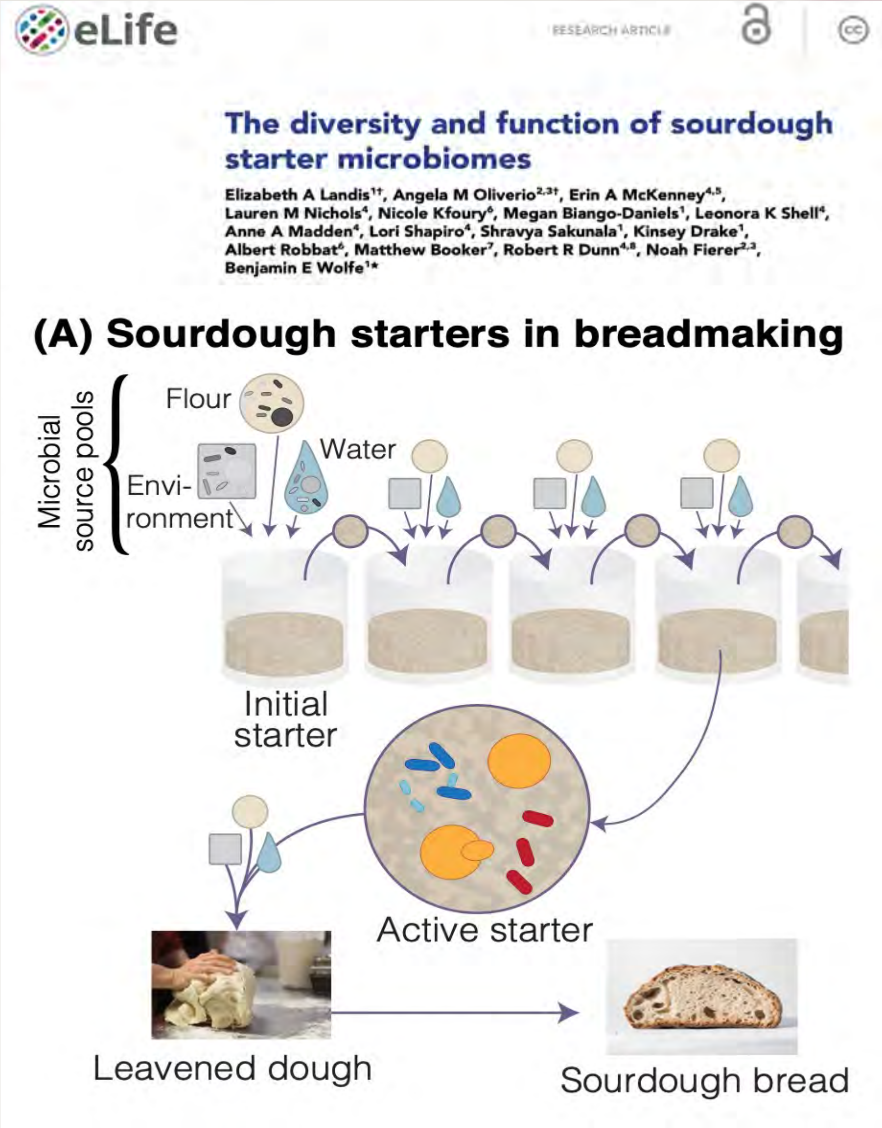
Source: Wang CC et al., 2021. https://www.science.org/doi/10.1126/science.abd9149



Ratio	Volume ratio
Sun:Earth	1304000
20 um:SARS-2	8000000
10 um:SARS-2	1000000
1 um:SARS-2	1000
20 um:E coli	8000
10 um:E coli	1000
1 um:E coli	1

Sun:Earth ratio from NASA.gov. Other ratios assume 0.1 mm sars-2 diameter, 1 µm E. coli diameter, treating microbes as spherical (questionable for E. coli). Image from https://starlust.org/how-big-is-the-sun/.

Sourdough and Buoyant Microbes



- Source: https://topwithcinnamon.com/how-to-make-a-sourdough-starter/, Landis et al., https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7837699/pdf/elife-61644.pdf.

SARS-CoV-2 vs. Measles

EVIDENCE SUPPORTING AIRBORNE TRANSMISSION	MEASLES	COVID-19
In lab setting, aerosolized virus is still viable (infectious) in the air after significant time has passed	**De Jong 1964** *Viable virus at 2 hours (less decay at low RH versus high RH)*	**van Doremalen 2020** *Viable virus at 3 hours without rapid decay despite high RH*
Viral RNA detected in aerosol samples and on low-/no- touch surfaces in absence of "AGMPs"	**Bischoff 2015**	**Chia 2020** **Lednicky 2020** **Santarpia 2020** *Highest surface contamination on floor and air exhaust grates*
Viable (infectious) virus cultured from aerosol samples		**Lednicky 2020** *Other pre-print studies pending peer-review*
Animal model showing viral transmission through the air	*Humans are only natural host*	**Richard 2020** **Kutter 2021** *Ferret model – including transmission > 1m and against gravity*
Outbreak investigations showing high likelihood of transmission over "long distances" (ie > 2m)	**Bloch 1985** – *Dr. office outbreak* **Remington 1985** – *Dr. office outbreak* **Riley 1978** – *School outbreak*	**Azimi 2021** – *Cruise outbreak model* **Eichler 2021** – *NZ quarantine hotel outbreak* **Günther 2020** – Meat processing outbreak **Miller 2020** – *Skagit choir outbreak*
Studies showing virus **within** HVAC vents/ducts	***Riley 1978*** *often quoted in literature as showing spread via HVAC, but several weaknesses and does NOT prove this**	**Nissen 2020** *+ RNA in HEPA filters, 5-7 floors above COVID+ patient areas, connected via ducts*
Nosocomial infections despite droplet and contact precautions used by HCWs		**Klompas 2021** **Klompas 2021** **Goldberg 2021**

[Table courtesy Dr. Jennifer MacDonald]

10 Reasons why SARS-CoV-2 is Airborne

- Greenhalgh et al., The Lancet 2021. https://doi.org/10.1016/S0140- 6736(21)00869-2

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

Heneghan and colleagues' systematic review, funded by WHO, published in March, 2021, as a preprint, states: "The lack of recoverable viral culture samples of SARS-CoV-2 prevents firm conclusions to be drawn about airborne transmission".[1] This conclusion, and the wide circulation of the review's findings, is concerning because of the public health implications.

If an infectious virus spreads predominantly through large respiratory droplets that fall quickly, the key control measures are reducing direct contact, cleaning surfaces, physical barriers, physical distancing, use of masks within droplet distance, respiratory hygiene, and wearing high-grade protection only for so-called aerosol-generating health-care procedures. Such policies need not distinguish between indoors and outdoors, since a gravity-driven mechanism for transmission would be similar for both settings. But if an infectious virus is mainly airborne, an

spread by droplets are airborne.[4] Ten streams of evidence collectively support the hypothesis that SARS-CoV-2 is transmitted primarily by the airborne route.[5]

First, superspreading events account for substantial SARS-CoV-2 transmission; indeed, such events may be the pandemic's primary drivers.[6] Detailed analyses of human behaviours and interactions, room sizes, ventilation, and other variables in choir concerts, cruise ships, slaughterhouses, care homes, and correctional facilities, among other settings, have shown patterns—eg, long-range transmission and overdispersion of the basic reproduction number (R_0), discussed below—consistent with airborne spread of SARS-CoV-2 that cannot be adequately explained by droplets or fomites.[6] The high incidence of such events strongly suggests the dominance of aerosol transmission.

Second, long-range transmission of SARS-CoV-2

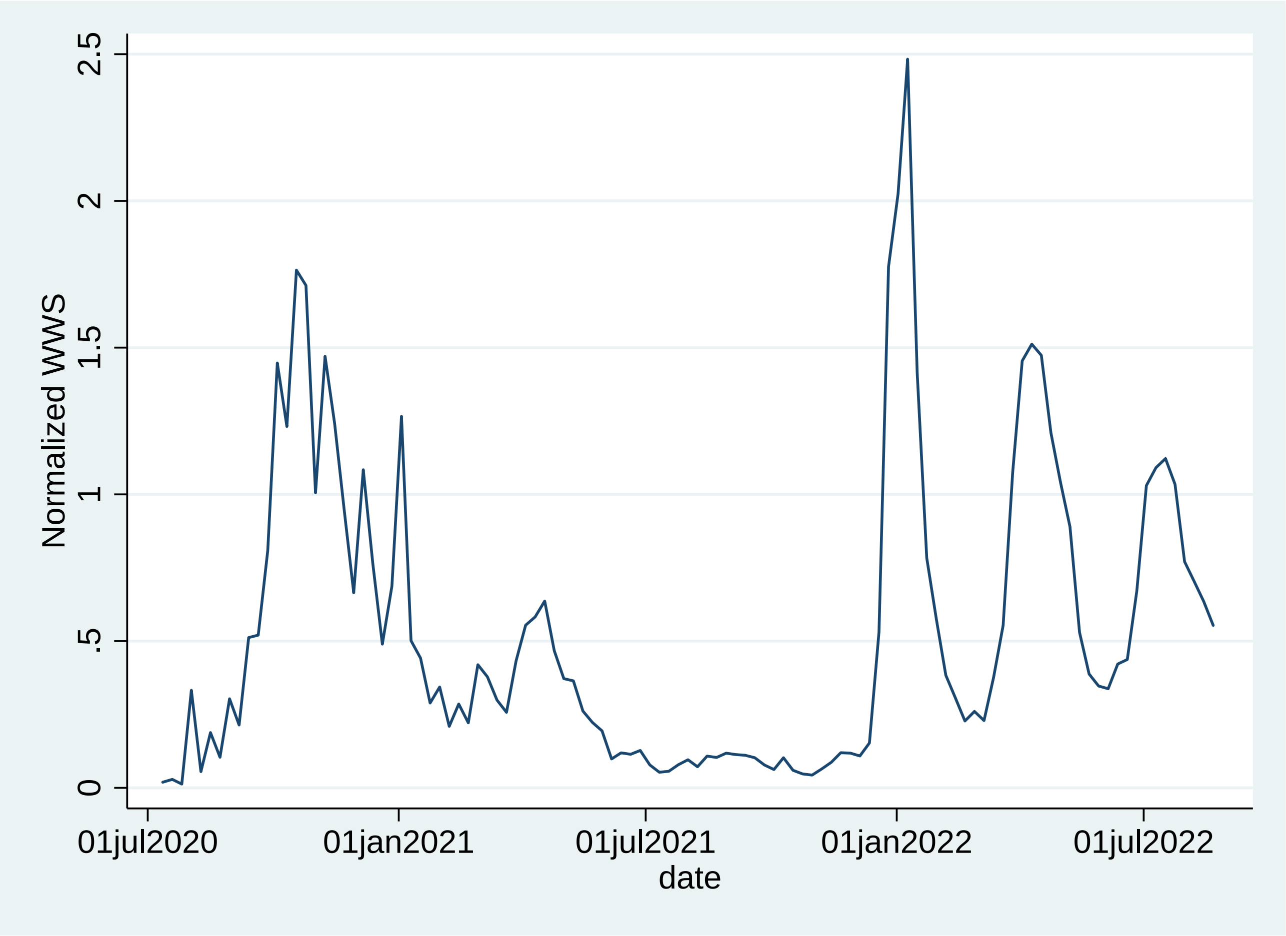
Published Online
April 15, 2021
https://doi.org/10.1016/S0140-6736(21)00869-2

This online publication has been corrected. The corrected version first appeared at thelancet.com on May 13, 2021

10 scientific reasons we know SARS-CoV-2 is airborne

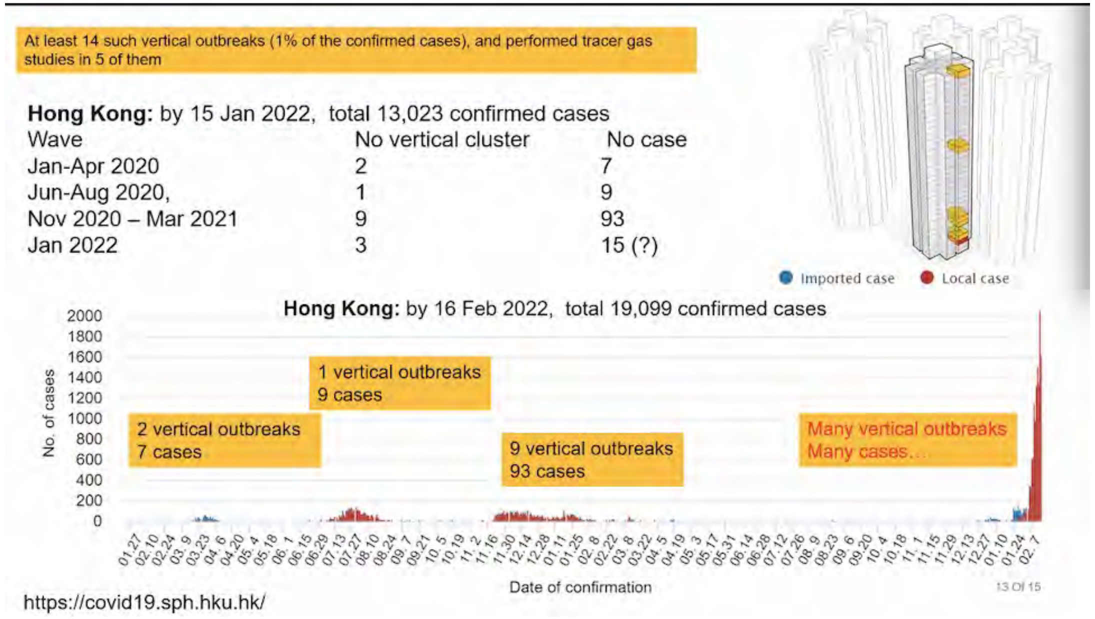
1. **Superspreading events** account for significant SARS-CoV-2 transmission.
2. **Long-range transmission** between people in adjacent rooms but never in each other's presence has been documented in quarantine hotels.
3. **Silent (w/out symptom) transmission** of SARS-CoV-2 from people who are not coughing or sneezing has been repeatedly demonstrated [key way COVID-19 has spread around the globe].
4. Transmission rates are **much higher indoors than outdoors**, and **reduced by indoor ventilation.**
5. **Nosocomial infections** have been carefully documented in healthcare organizations even when using strict contact-and-droplet precautions and PPE designed to protect against droplet but not aerosol exposure.
6. **Viable SARS-CoV-2 has been detected in the air.**
7. SARS-CoV-2 virus has been identified in **air filters and building ducts** in hospitals housing COVID-19 patients, locations that could be reached only by aerosols.
8. Studies on **caged animals** have shown patterns consistent with aerosol transmission but no evidence of transmission from fomites.
9. There is a **lack of disconfirming evidence**. No study has provided strong or consistent evidence to refute the hypothesis that SARS-CoV-2 is airborne.
10. **Evidence supporting other routes of transmission (droplet or fomite) is very weak.**[8,20] Ease of infection in close proximity has been incorrectly used as "proof" of droplet transmission.

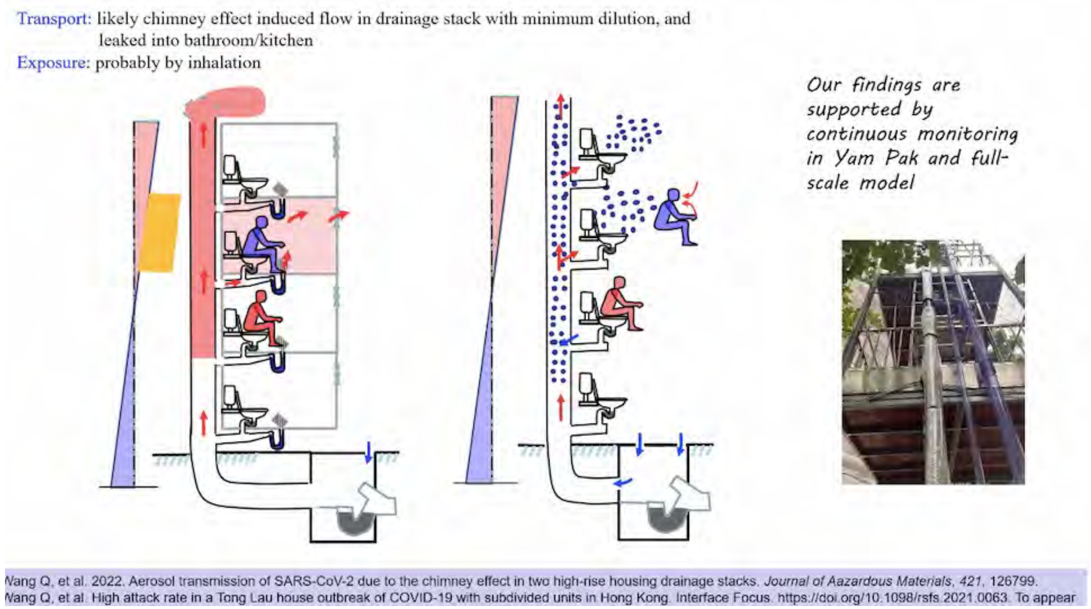
Normalized Ontario WWS from July 12, 2020 to September 4, 2022



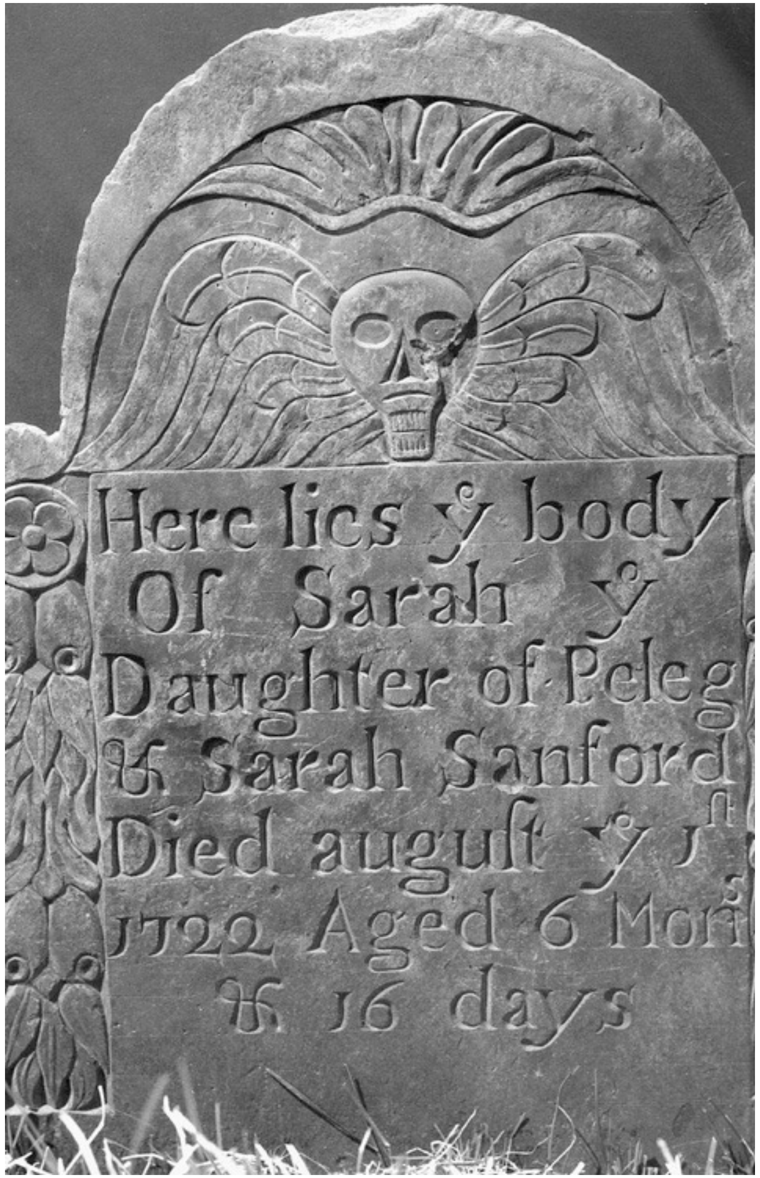
Fecal Aerosols: Miasma Redux

- [Slides: Dr. Yougo Li, ECCMID pre-meeting 2022]



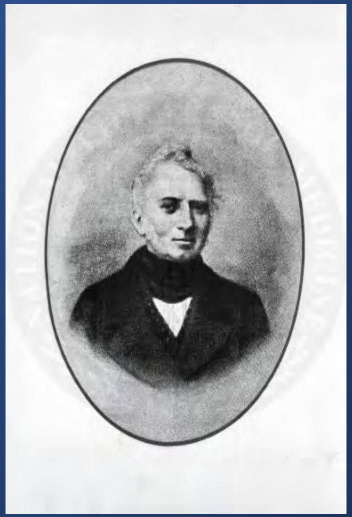


Historical origins of present-day messaging



"And this also," said Marlow suddenly, "has been one of the dark places of the earth."
-Joseph Conrad, Heart of Darkness

- [Images: Center for History and New Media, George Mason University, and Wikimedia Commons]



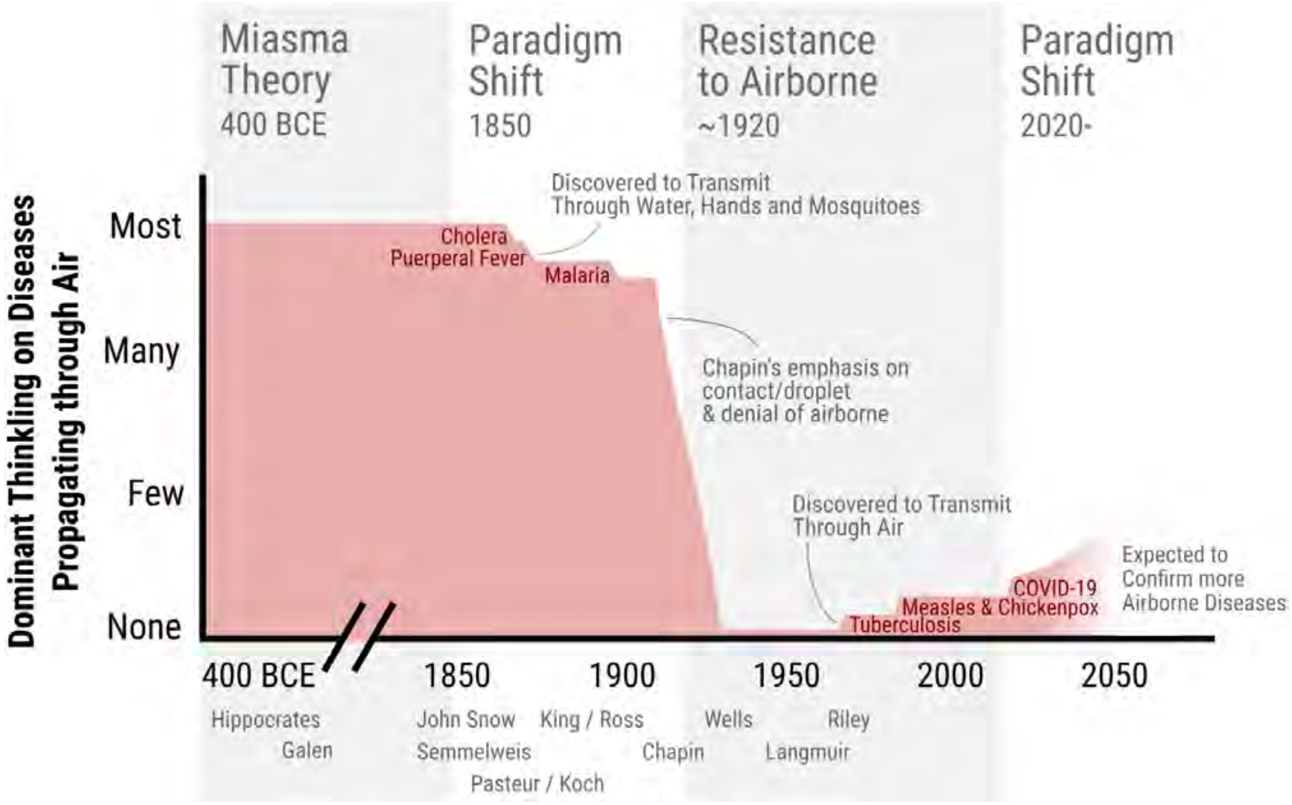
Snow's "Literature Review" and Pamphlet (1848)

- **Miasma:** mathematical model! Knowledge of gas laws makes miasma implausible.
- **Clinical and pathological focus**: symptoms and irritation of gut suggest agent ingested.
- **Epidemiologic pillars:**
  - Centrality of humans to transmission (sick travelers).
  - Short- and long-distance transmission: Snow focusses on feces as likely culprit (hands and sewage).
  - Able to link cholera occurrence presence or absence of sewage in drinking water in 7 London neighborhoods and 17 provincial towns.
- Tenacity: Snow a vocal minority for 7 years on cholera.

Mechanistic Understanding and Disease Control
[Mary Ross, CJPH 1935, note log scale]

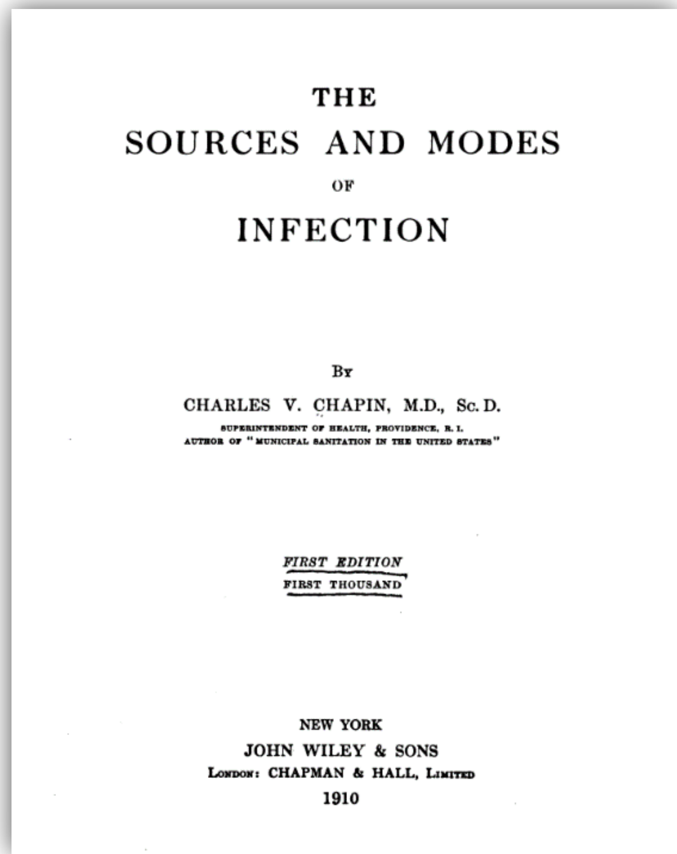
FIGURE I—TYPHOID FEVER—ONTARIO. Mortality Rate per 100,000, 1880-1931.

What were the historical reasons for the resistance to recognizing airborne transmission during the COVID-19 pandemic?



Indoor Air, Volume: 32, Issue: 8, First published: 21 August 2022, DOI: (10.1111/ina.13070)

Charles Chapin


THE
SOURCES AND MODES
OF
INFECTION

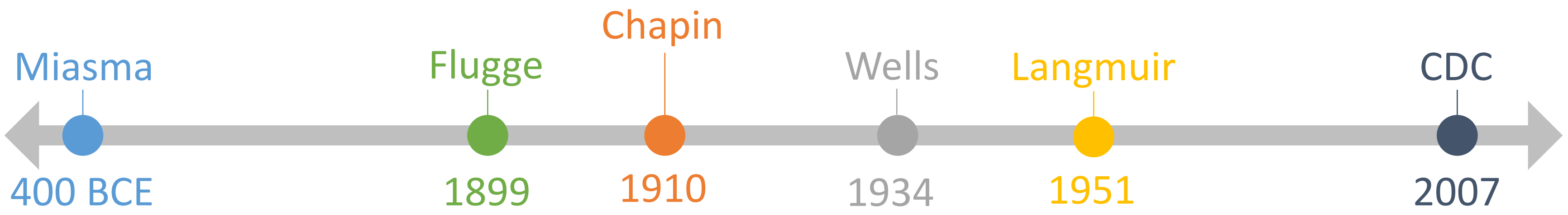
By
CHARLES V. CHAPIN, M.D., Sc. D.
SUPERINTENDENT OF HEALTH, PROVIDENCE, R. I.
AUTHOR OF "MUNICIPAL SANITATION IN THE UNITED STATES"

FIRST EDITION
FIRST THOUSAND

NEW YORK
JOHN WILEY & SONS
LONDON: CHAPMAN & HALL, LIMITED
1910

"**Contact** infection...affords a better explanation of the [theory of aerial transmission of disease]... ideas in regard air-borne [diseases] are entirely erroneous...they are spray-borne for only two or three feet...which resembles **contact** infection." (p. 263)

Slide courtesy Prof. Linsey Marr



William and Mildred Wells

Slide courtesy of Prof. Linsey Marr

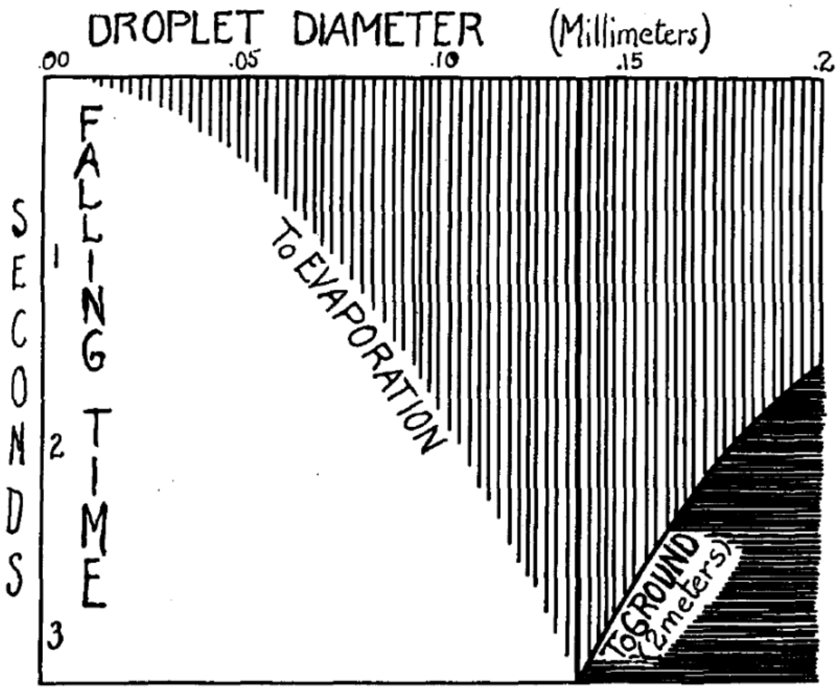
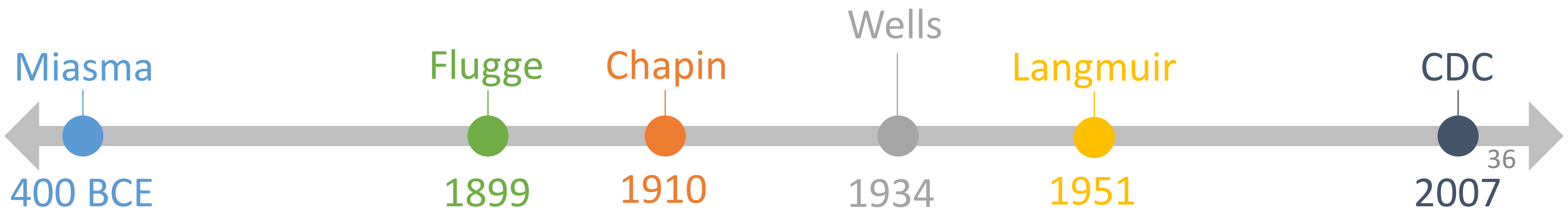


CHART 1. Falling times and evaporation times of droplets of varying diameter.

"<u>droplet infection</u>...applies to droplets larger than [100 μm], which are rapidly removed from the air by gravity...within a short distance of the source."

"<u>air-borne infection</u>...derived directly from droplets less than [100 μm] diameter...long times and carries them long distances."

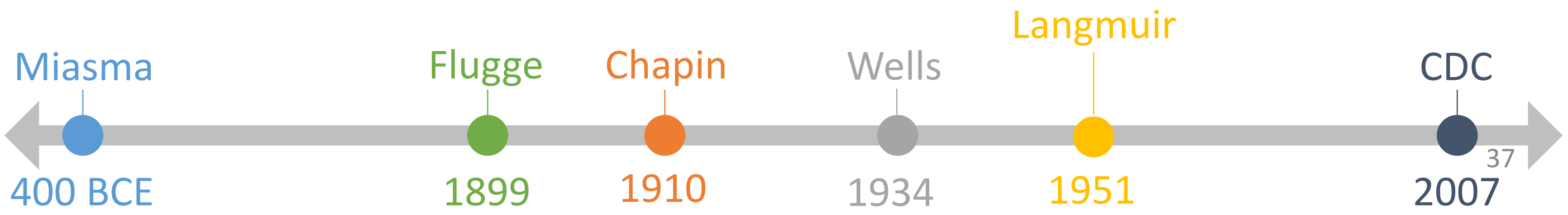


Langmuir

- "It remains to be proved that airborne infection is an important mode of spread of naturally occurring disease" but later emphasized *artificial* spread via bioweapons
- In the 1980s, he acknowledged that certain diseases were airborne

CENTERS FOR DISEASE CONTROL AND PREVENTION

Epidemic Intelligence Service



Wells and Riley—TB is Airborne

- Guinea pigs housed above L-shaped air ducts in Baltimore VA TB ward.
- Demonstrated direct infection via air.
- Demonstrated germicidal UV effects (UV in ducts prevents infection).

AERIAL DISSEMINATION OF PULMONARY TUBERCULOSIS

A TWO-YEAR STUDY OF CONTAGION IN A TUBERCULOSIS WARD[1]

By

R. L. RILEY, C. C. MILLS, W. NYKA, N. WEINSTOCK, P. B. STOREY, L. U. SULTAN, M. C. RILEY AND W. F. WELLS[2]

(Received for publication March 26, 1959)

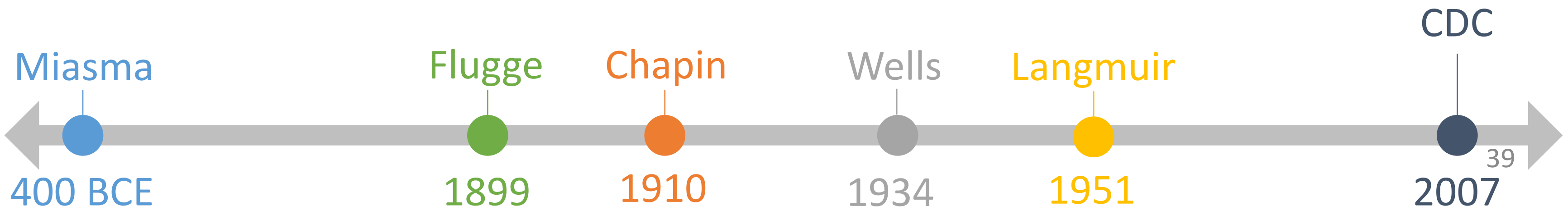
Source: https://pubmed.ncbi.nlm.nih.gov/7785671/

2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings

"Droplets traditionally have been defined as being >5 µm in size. Droplet nuclei, particles arising from desiccation of suspended droplets, have been associated with airborne transmission and defined as ≤5 µm in size."

https://www.wired.com/story/the-teeny-tiny-scientific-screwup-that-helped-covid-kill/

Slide courtesy of Prof. Linsey Marr



Scientific Archeology

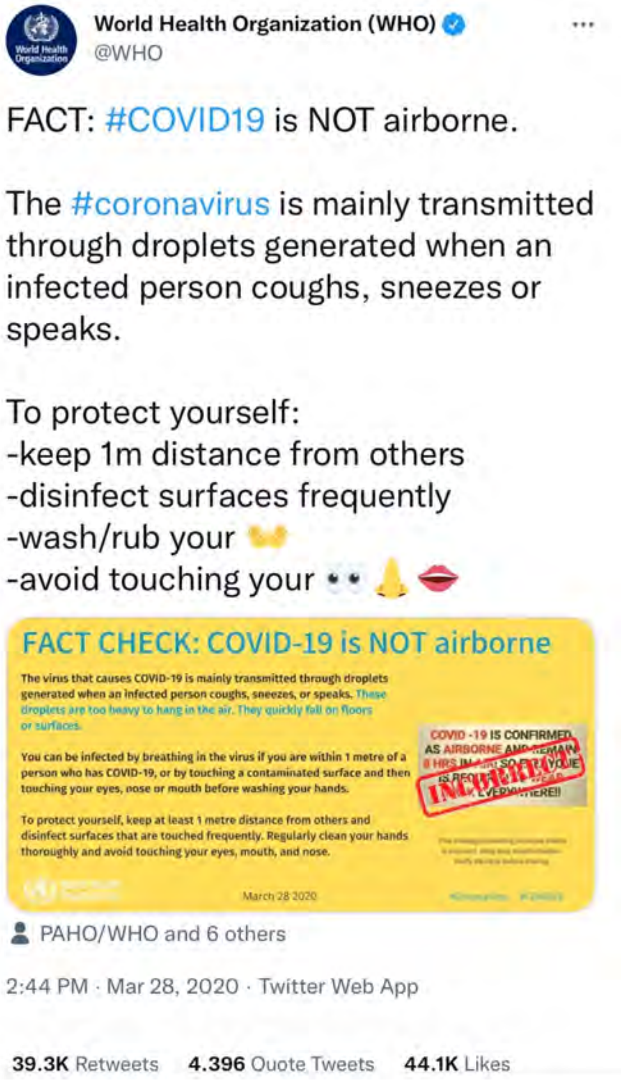
Source: https://www.wired.com/story/the-teeny-tiny-scientific-screwup-that-helped-covid-kill/

MEGAN MOLTENI BACKCHANNEL MAY 13, 2021 6:00 AM

The 60-Year-Old Scientific Screwup That Helped Covid Kill

All pandemic long, scientists brawled over how the virus spreads. *Droplets! No, aerosols!* At the heart of the fight was a teensy error with huge consequences.

Poor and Outdated Messaging from Institutional Public Health



A Key Failure of the Pandemic Response

- Source: Sachs et al., *Lancet,* https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(22)01585-9/fulltext

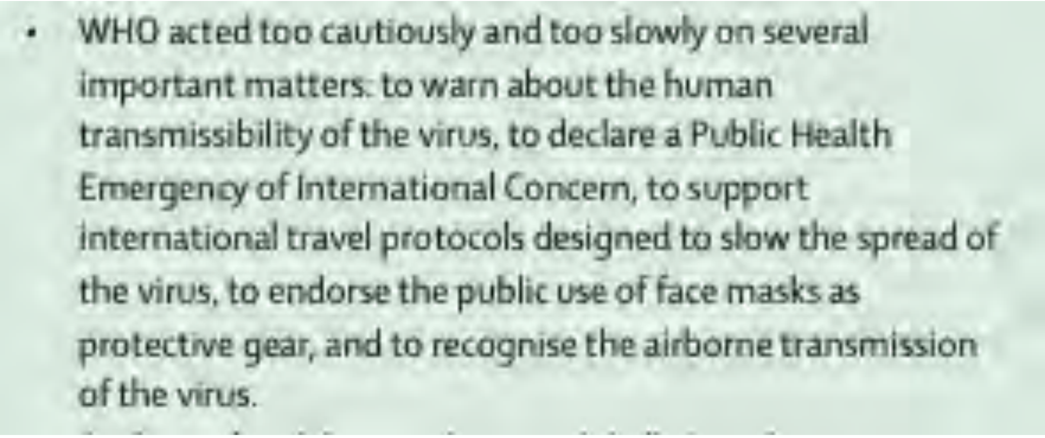
The *Lancet* Commission on lessons for the future from the COVID-19 pandemic

Jeffrey D Sachs, Salim S Abdool Karim, Lara Aknin, Joseph Allen, Kirsten Brosbøl, Francesca Colombo, Gabriela Cuevas Barron, María Fernanda Espinosa, Vitor Gaspar, Alejandro Gaviria, Andy Haines, Peter J Hotez, Phoebe Koundouri, Felipe Larraín Bascuñán, Jong-Koo Lee, Muhammad Ali Pate, Gabriela Ramos, K Srinath Reddy, Ismail Serageldin, John Thwaites, Vaira Vike-Freiberga, Chen Wang, Miriam Khamadi Were, Lan Xue, Chandrika Bahadur, Maria Elena Bottazzi, Chris Bullen, George Laryea-Adjei, Yanis Ben Amor, Ozge Karadag, Guillaume Lafortune, Emma Torres, Lauren Barredo, Juliana G E Bartels, Neena Joshi, Margaret Hellard, Uyen Kim Huynh, Shweta Khandelwal, Jeffrey V Lazarus, Susan Michie

Lancet 2022; 400: 1224–80

Executive summary

and peace that governments are committed to pursue as



- WHO acted too cautiously and too slowly on several important matters: to warn about the human transmissibility of the virus, to declare a Public Health Emergency of International Concern, to support international travel protocols designed to slow the spread of the virus, to endorse the public use of face masks as protective gear, and to recognise the airborne transmission of the virus.

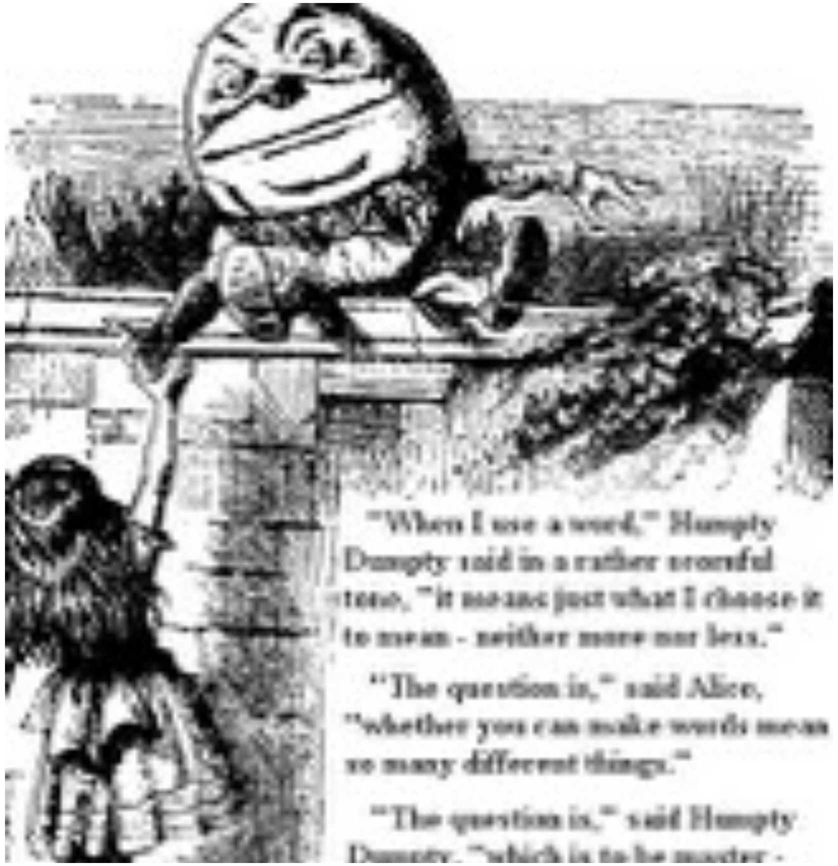
Airborne Means Airborne

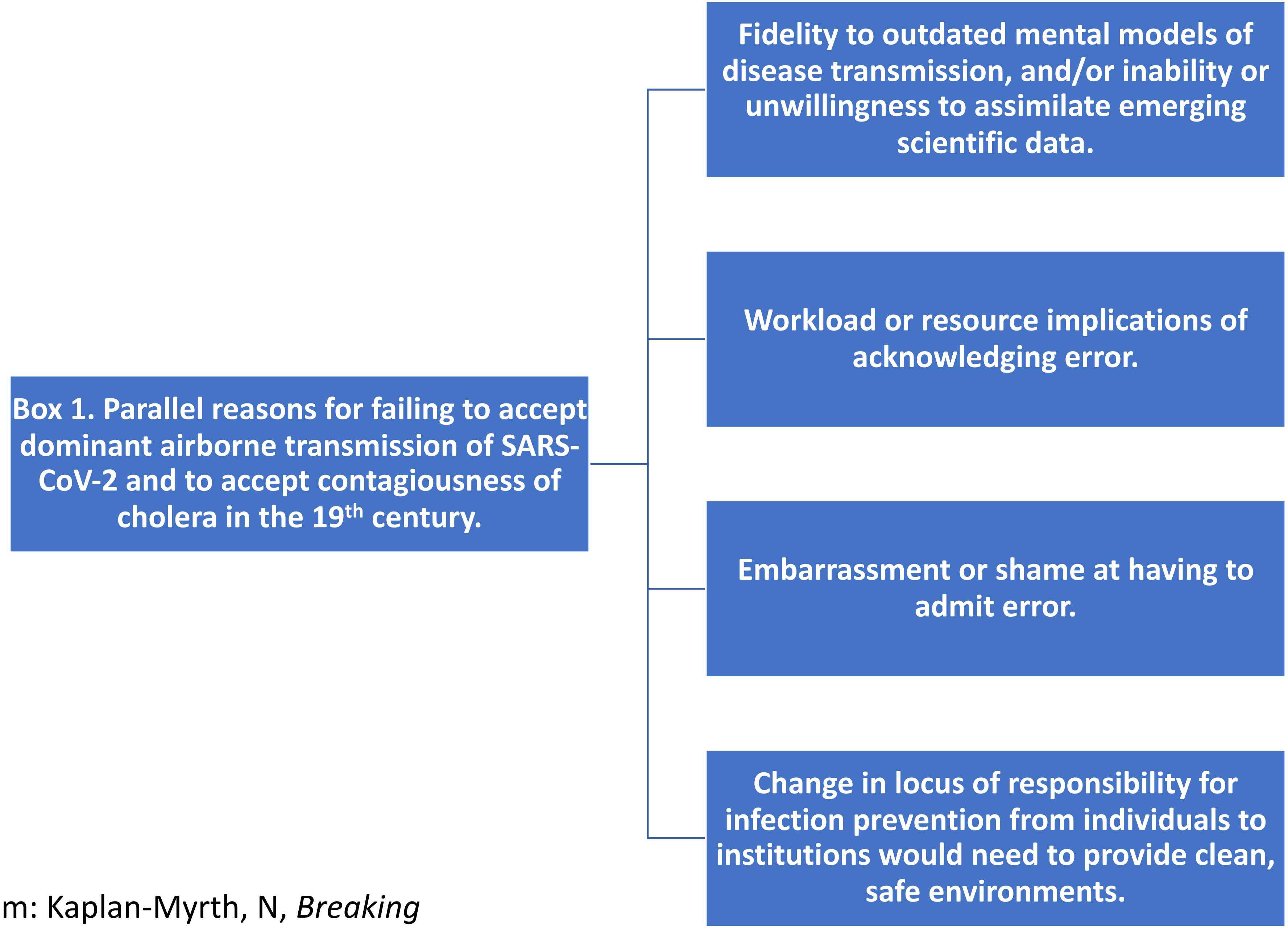
“When I use a word,’ Humpty Dumpty said in rather a scornful tone, ‘it means just what I choose it to mean — neither more nor less.’

’The question is,’ said Alice, ‘whether you can make words mean so many different things.’

’The question is,’ said Humpty Dumpty, ‘which is to be master — that’s all.”

— Lewis Carroll, Through the Looking Glass





Adapted from: Kaplan-Myrth, N, *Breaking Canadians*, 2024.

Tools for control

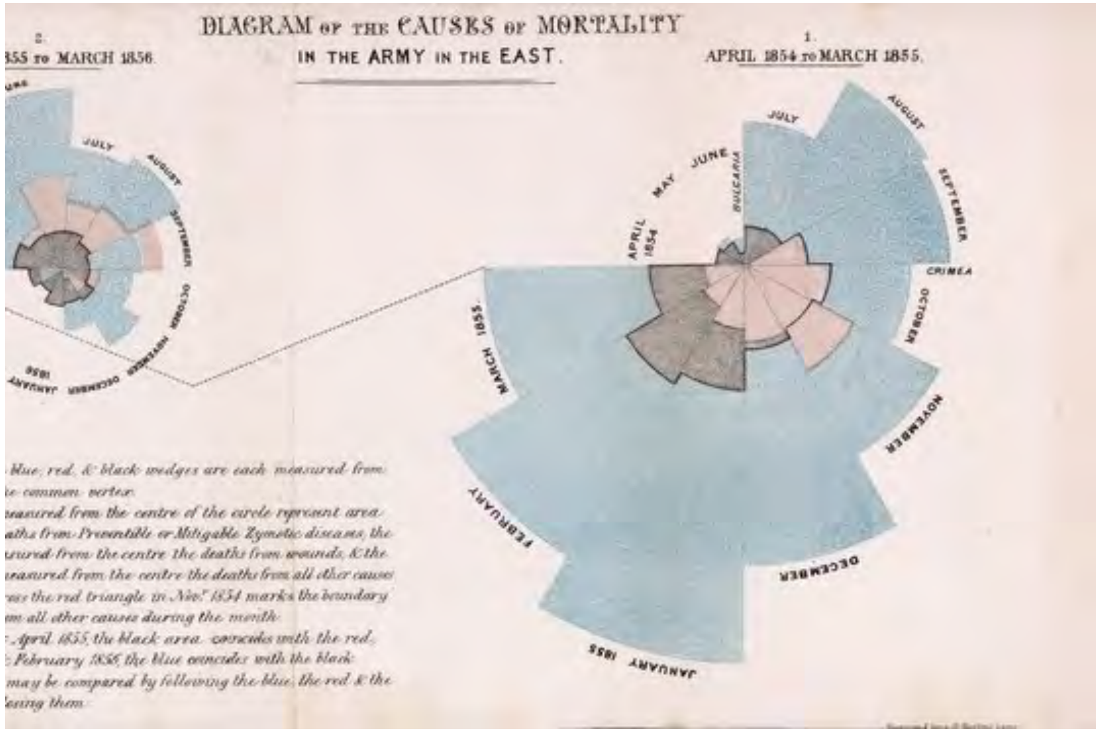
Basic tools for managing infective aerosols

- Ventilation (replace dirty air with fresh air).
  - Outdoor activities.
- Filtration (take particles out of the air).
  - Masks and respirators.
- Disinfection (usually with germicidal UV radiation).
- Information (informs interventions and allows people to protect themselves).

Mechanistic Understanding and Disease Control
[Mary Ross, CJPH 1935, note log scale]

FIGURE I—TYPHOID FEVER—ONTARIO. Mortality Rate per 100,000, 1880-1931.

Outdoor Air: Rediscovering Lost Wisdom



Sarah Zhang, The Atlantic, 2021

Ventilation

POLICY FORUM

INFECTIOUS DISEASE

A paradigm shift to combat indoor respiratory infection

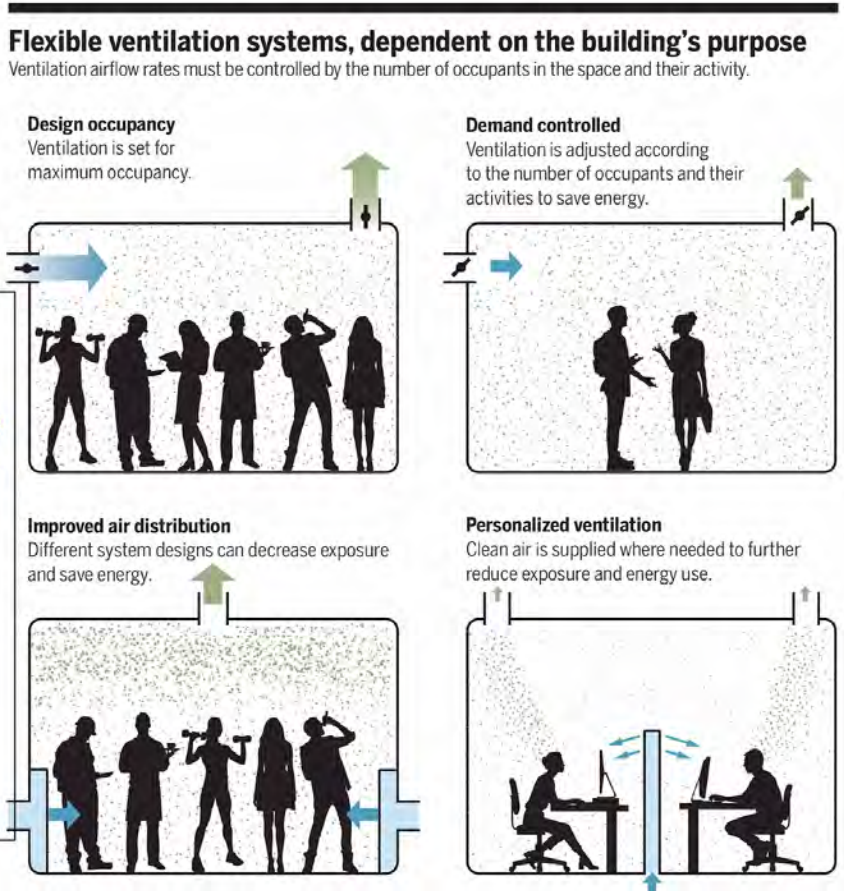
Building ventilation systems must get much better

Air changes per hour (ACH)

Number of times in one hour that air volume of a space is supplied with either outdoor air or air that has been pushed through a filter

- Homes: 1 ACH
- Hospitals: 6-12 ACH (ever 10 to 5 minutes)
- Schools: <2 ACH (*much less in reality)

Morawska, et al. 2021, Science



Slide courtesy of Dr. Kim Prather

Impact of Acknowledging Airborne Transmission (1)

TABLE 2. COVID-19 incidence* and rate ratios in 123 elementary schools,[†] by type of ventilation improvement as a COVID-19 prevention strategy — Georgia, November 16–December 11, 2020

Return

Ventilation improvement	No. (%) of schools	No. of enrolled students	No. of cases[§]	Cases per 500 students enrolled (95% CI)	RR[¶] (95% CI)
Total	**123 (100)**	**66,499**	**417**	**3.13 (2.84–3.44)**	**—**
None**	37 (30.1)	21,844	183	4.19 (3.63–4.84)	Ref
Dilution only[††]	39 (31.7)	21,562	127	2.94 (2.48–3.50)	0.65 (0.43–0.98)
Filtration ± purification only[§§]	16 (13.0)	9,133	45	2.46 (1.84–3.29)	0.69 (0.40–1.21)
Dilution and filtration ± purification[¶¶]	31 (25.2)	13,960	62	2.22 (1.73–2.84)	0.52 (0.32–0.83)

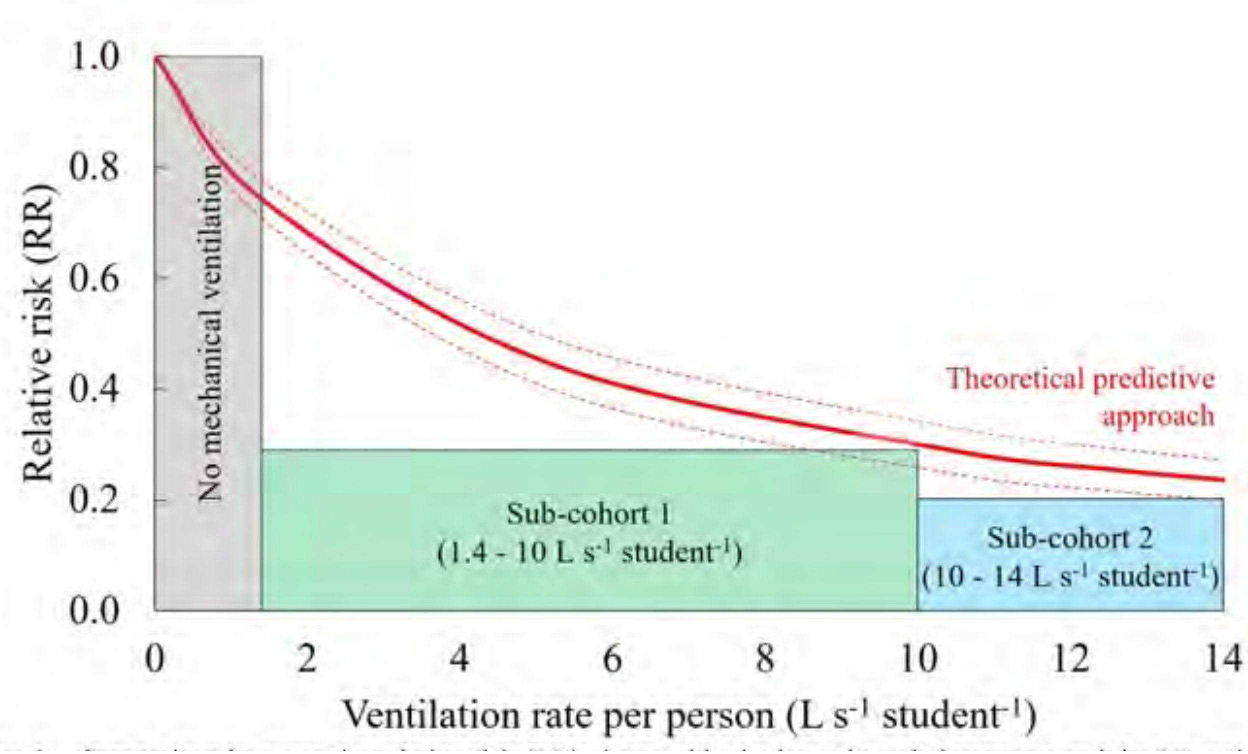
Source: Gettings et al., MMWR 2021, https://www.cdc.gov/mmwr/volumes/70/wr/mm7021e1.htm

Retrospective Cohort Study

The study represents a Halley's comet because we have had simultaneous (i) waves of infections (Delta and Omicron); (ii) different levels of ventilation in school classrooms; and (iii) monitoring of infections.

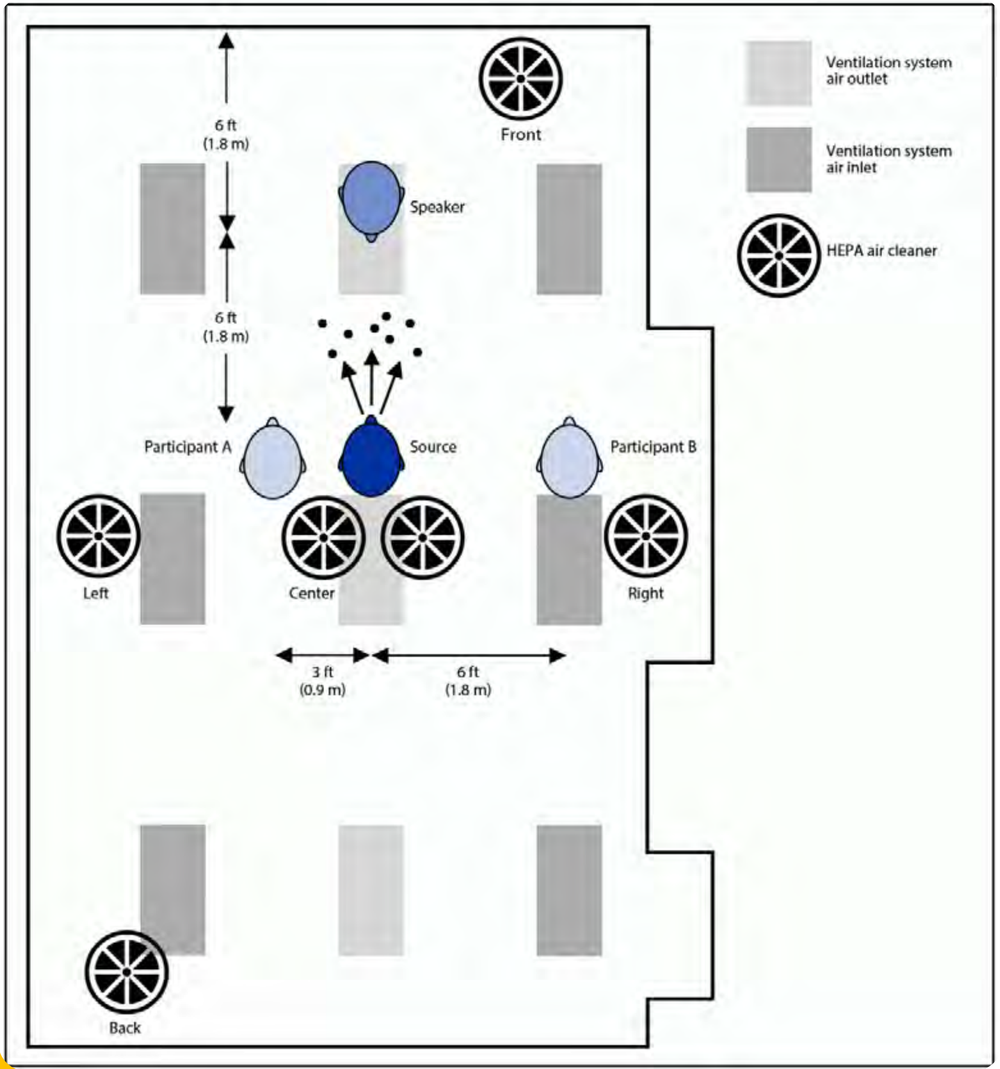
The ventilation works…

Validation of the approach through a retrospective cohort study. Possibility of extending the use of the approach, once the scenario has been defined, to any indoor environment of interest.



Slide courtesy Professor Giorgio Buonanno.

Buonanno G, Ricolfi L, Morawska L and Stabile L (2022) Increasing ventilation reduces SARS-CoV-2 airborne transmission in schools: A retrospective cohort study in Italy's Marche region. *Front. Public Health* 10:1087087. doi: 10.3389/fpubh.2022.1087087

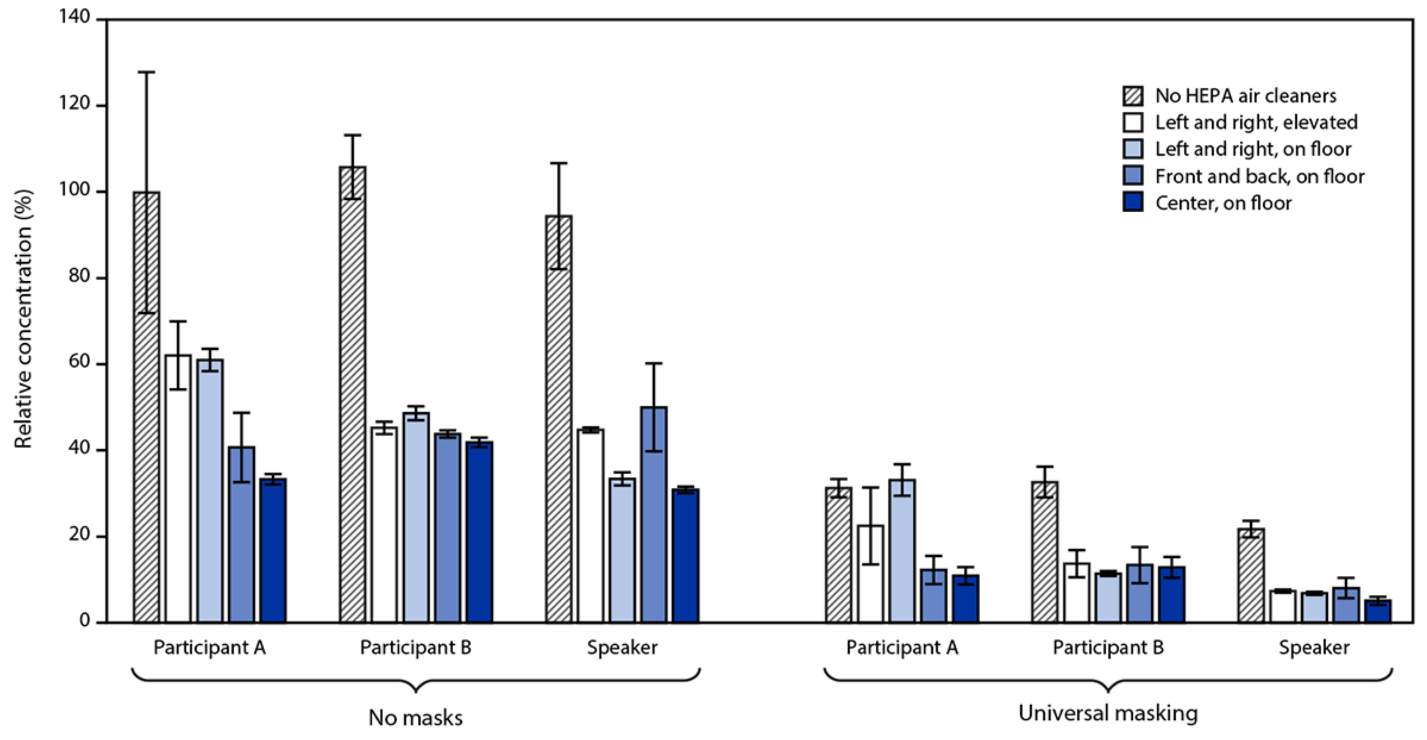


Filtration

- Can remove small particles from air using commercial air cleaners with HEPA filters.
- Removed around 2/3 of simulated COVID aerosols in CDC study.
- Synergy with masks: 90% reduction in aerosols.

- Lindsley WG, Derk RC, Coyle JP, et al. Efficacy of Portable Air Cleaners and Masking for Reducing Indoor Exposure to Simulated Exhaled SARS-CoV-2 Aerosols — United States, 2021. MMWR Morb Mortal Wkly Rep 2021;70:972–976. DOI: http://dx.doi.org/10.15585/mmwr.mm7027e1external icon.

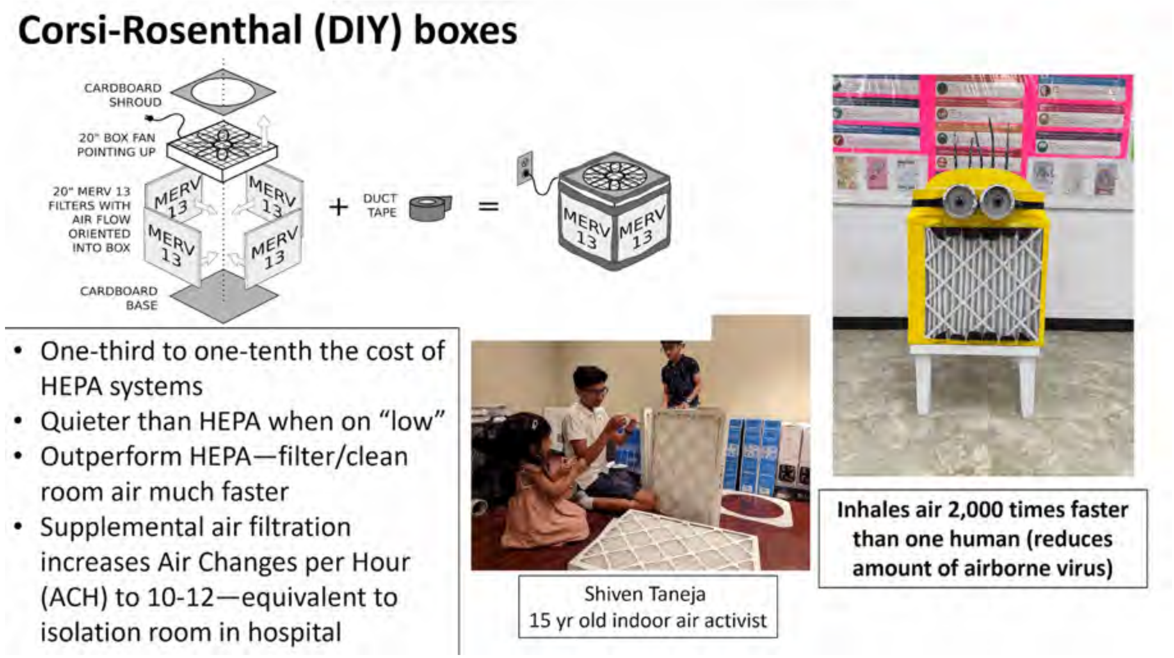
Filtration (2)



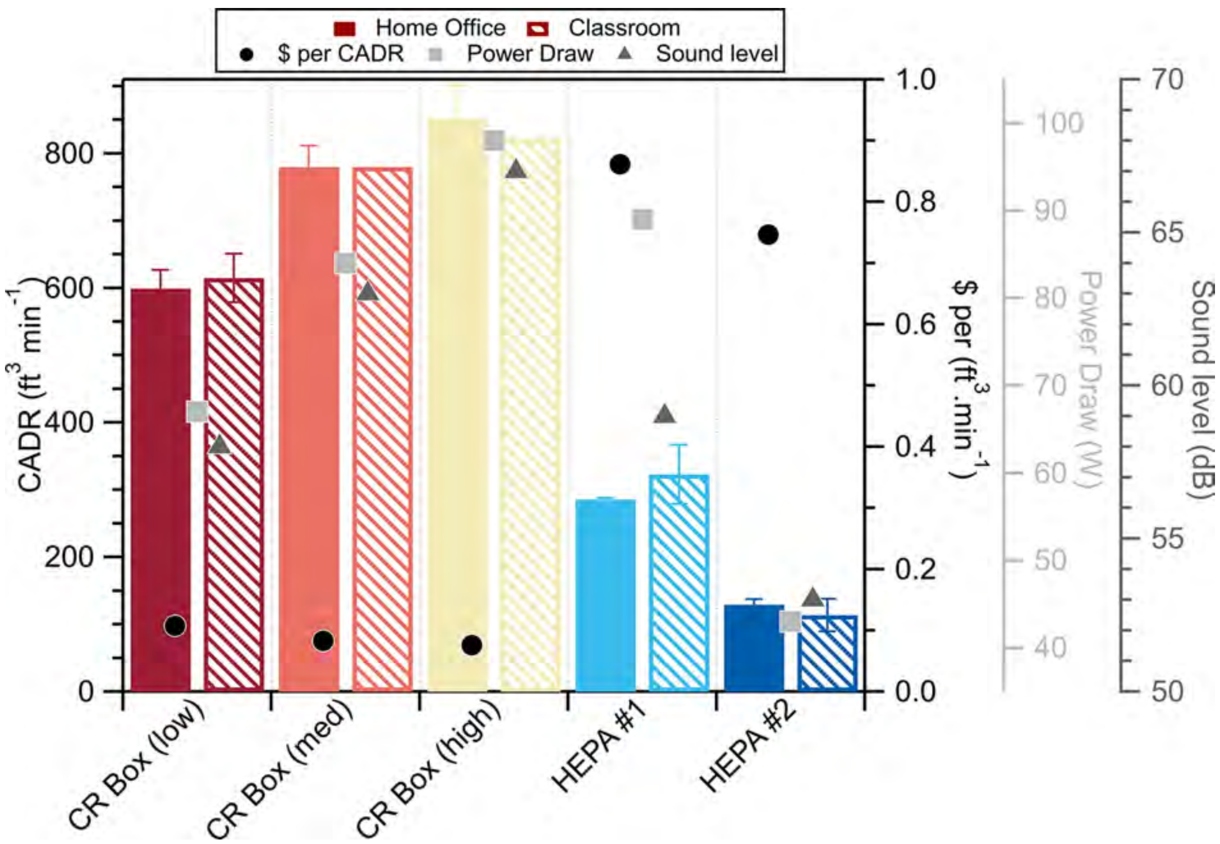
- Lindsley WG, Derk RC, Coyle JP, et al. Efficacy of Portable Air Cleaners and Masking for Reducing Indoor Exposure to Simulated Exhaled SARS-CoV-2 Aerosols — United States, 2021. MMWR Morb Mortal Wkly Rep 2021;70:972–976. DOI: [http://dx.doi.org/10.15585/mmwr.mm7027e1external icon](http://dx.doi.org/10.15585/mmwr.mm7027e1).

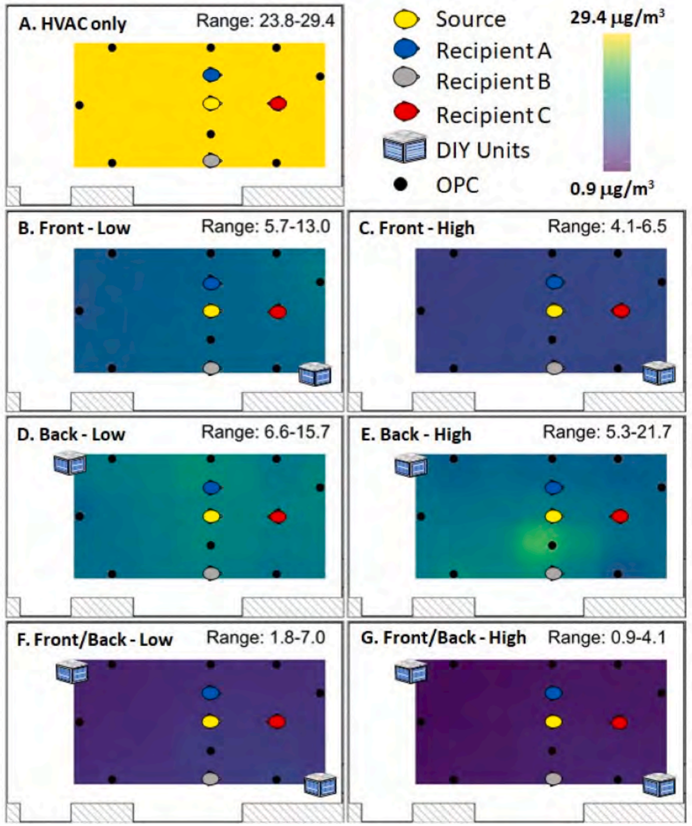
Filtration: The DIY Revolution!

- Slides courtesy of Dr. Kim Prather



Emerging Peer-Reviewed Science on CR Boxes

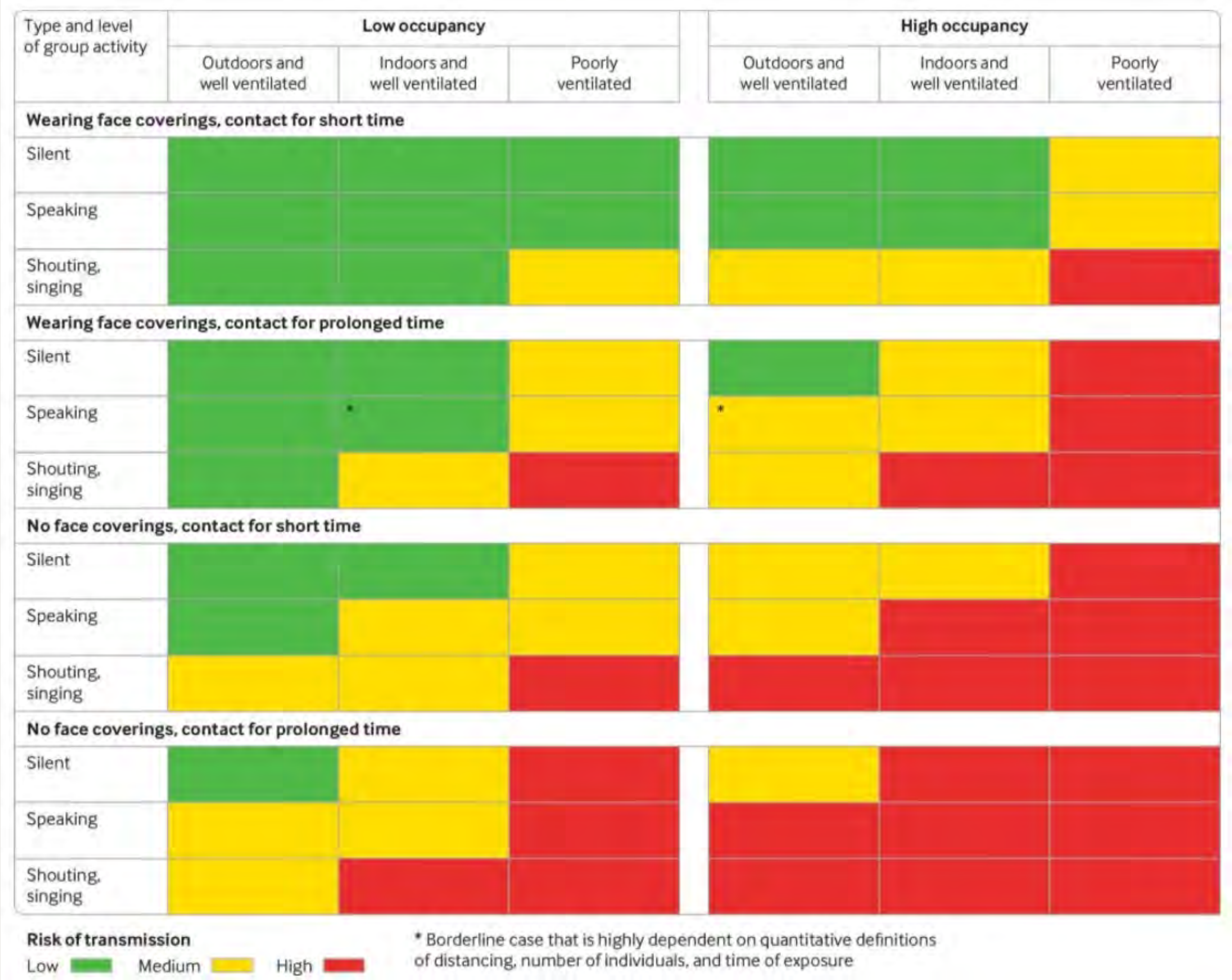




Rachael Dal Porto, Monet N. Kunz, Theresa Pistochini, Richard L. Corsi & Christopher D. Cappa (2022) Characterizing the performance of a do-it-yourself (DIY) box fan air filter, Aerosol Science and Technology, 56:6, 564-572, DOI: 10.1080/02786826.2022.2054674 and Srikrishna D. Can 10× cheaper, lower-efficiency particulate air filters and box fans complement High-Efficiency Particulate Air (HEPA) purifiers to help control the COVID-19 pandemic? Sci Total Environ. 2022 Sep 10;838(Pt 1):155884. doi: 10.1016/j.scitotenv.2022.155884.

University of Calgary debate, April 2021.

Overcoming the 4 C's.

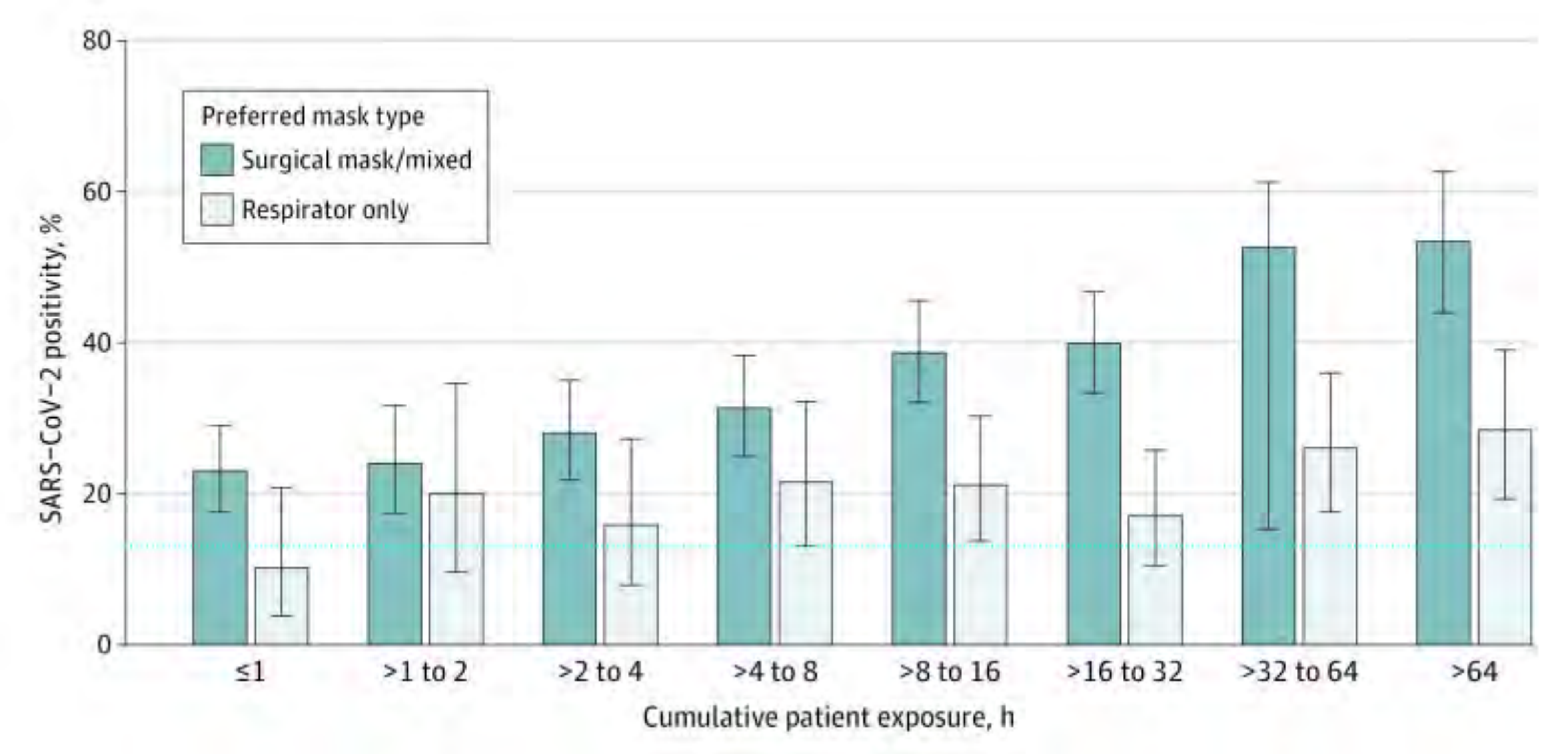


Source: https://www.bmj.com/content/370/bmj.m3223

Impact of Acknowledging Airborne Transmission (2)

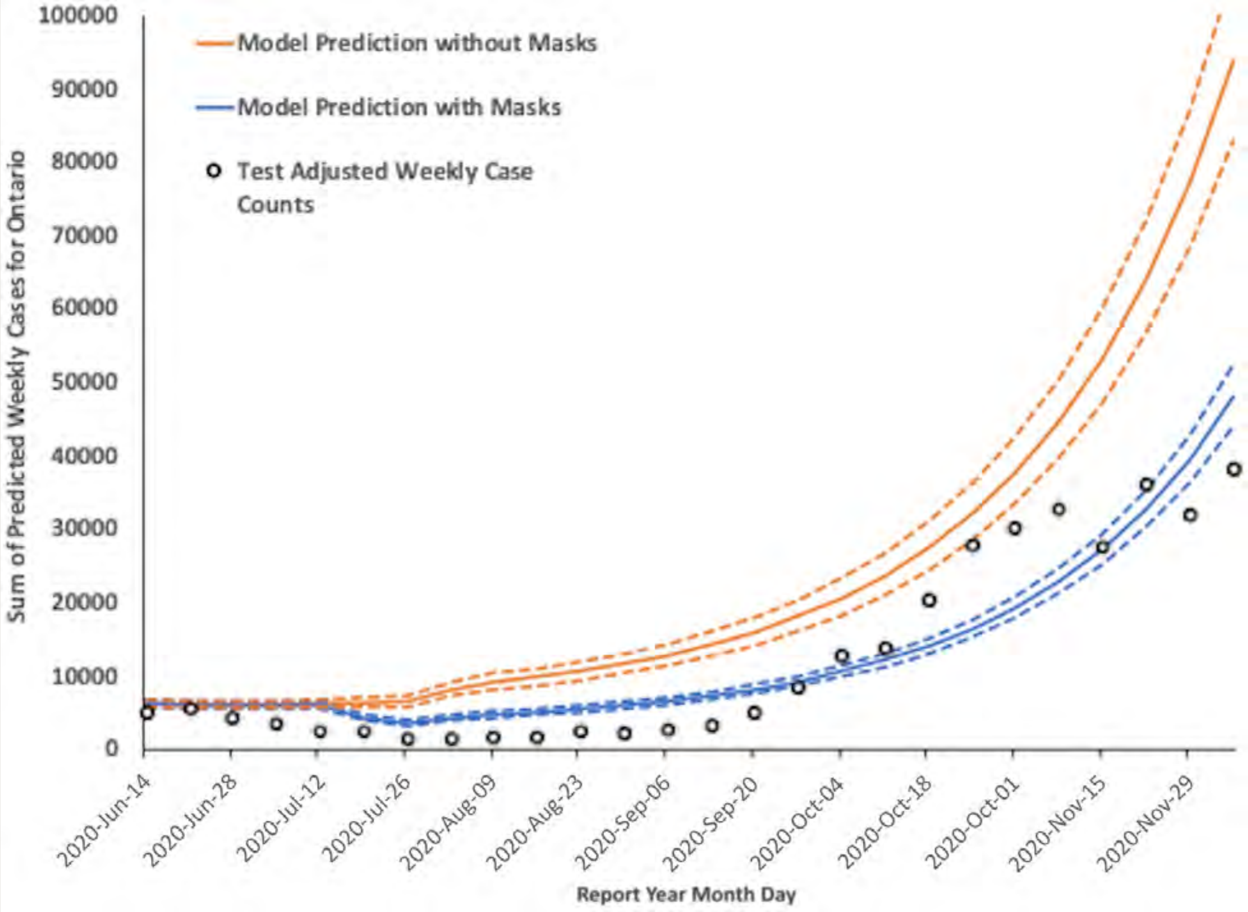
Source: Andrejko et al., MMWR 2022, https://www.cdc.gov/mmwr/volumes/71/wr/mm7106e1.htm

Impact of Acknowledging Airborne Transmission (3)



Source: Dörr et al., JAMA Network Open 2022, https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2795150

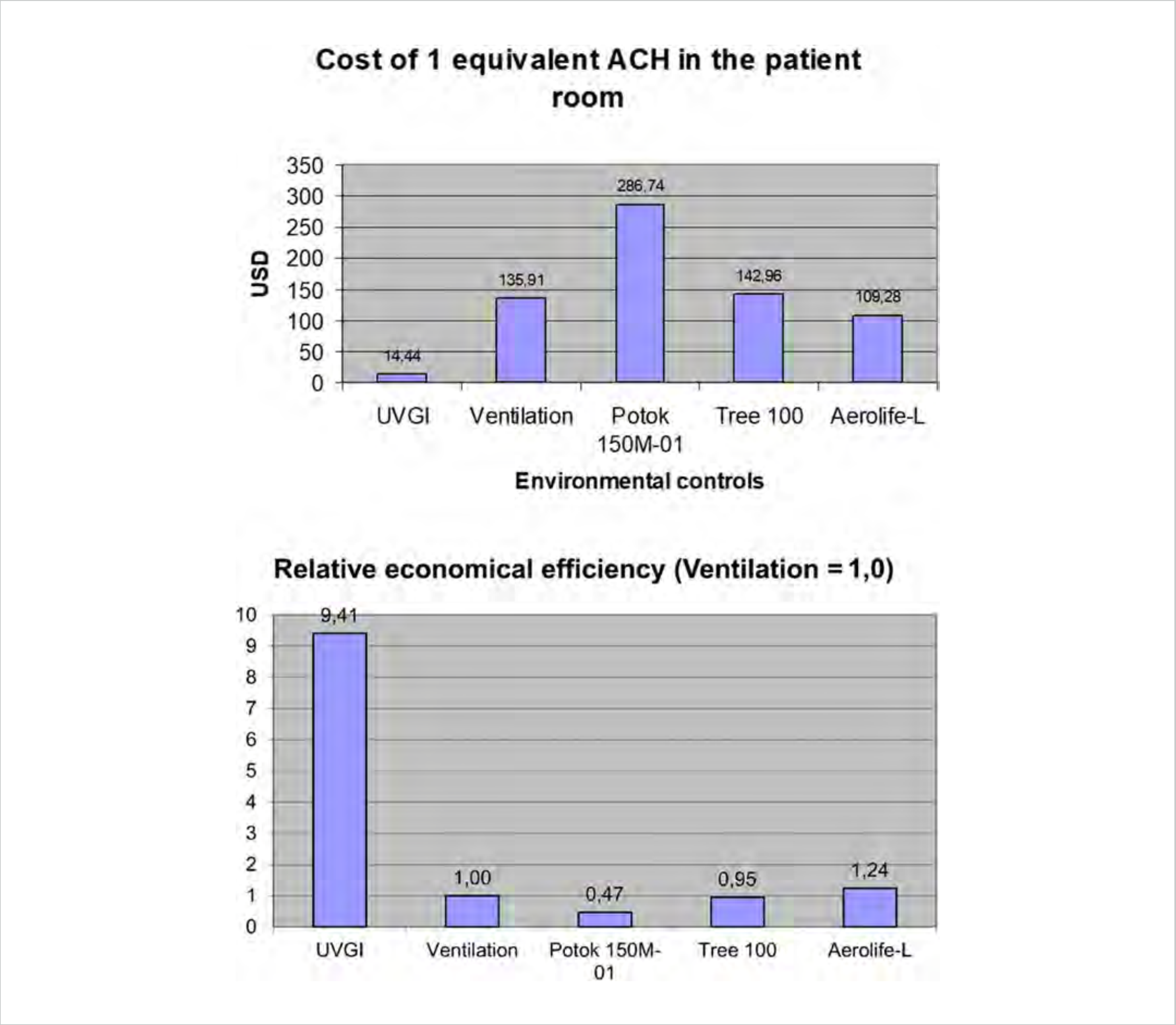
Fig. 4. Model-based estimation of mask mandate impact. Test-adjusted weekly case counts (circles) were used to fit a ...



PNAS Nexus, Volume 3, Issue 2, February 2024, pgae065, https://doi.org/10.1093/pnasnexus/pgae065

Germicidal UV

- Old technology (in use since the 1940s), inexpensive.
  - Commonly used in homeless shelters for preventing TB transmission.
- UVC radiation destroys DNA and RNA in bacteria and viruses.
- High room, probably needs to be complemented with enhanced ventilation/filtration.
- Figure: Dr. Ed Nardell, https://onlinelibrary.wiley.com/doi/10.1111/php.13421
- Emerging **far UV** (krypton-based) is promising.



Far UV

Photochemistry and Photobiology

INVITED REVIEW | Open Access |

The public-health significance of far-UVC-induced indoor ozone and its associated secondary chemistry

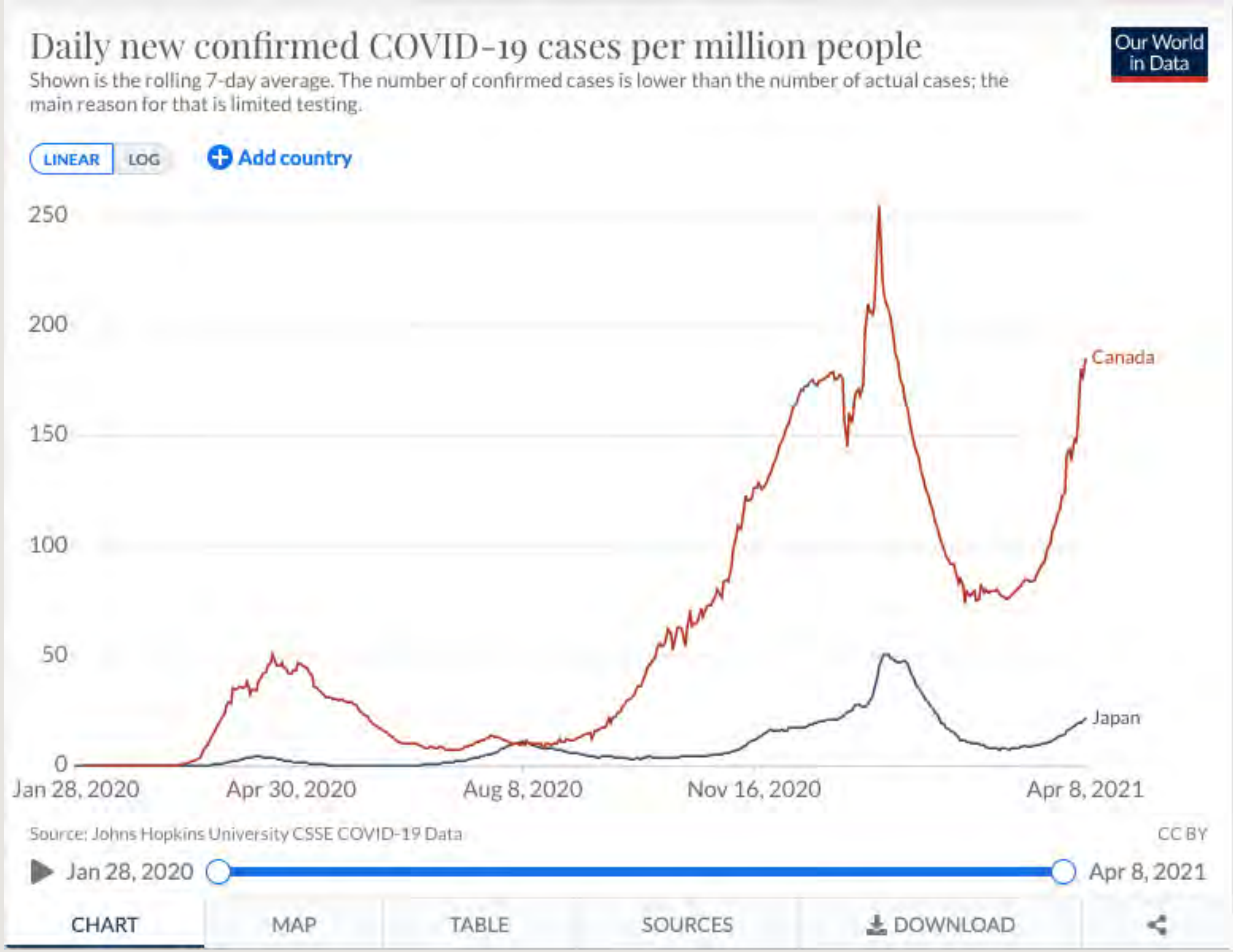
David J. Brenner

First published: 30 November 2023 | https://doi.org/10.1111/php.13892

Ref: https://onlinelibrary.wiley.com/doi/10.1111/php.13892

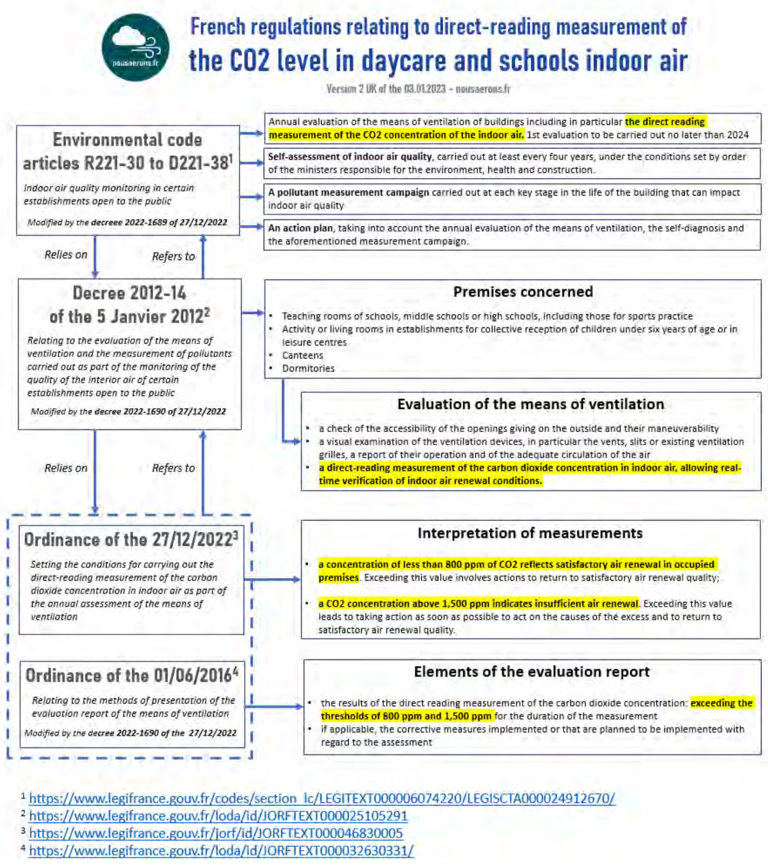
Japan and Canada: A Study in Contrasts

University of Calgary debate, April 2021.



Information

Co2: Monitoring and Regulation



Belgium imposes ventilation rules for businesses to combat new Covid surge

Carbon dioxide monitors must be on public display so customers can see level of fresh air

Indoor Air and Public Health Surveillance

Normalized Ontario WWS from July 12, 2020 to September 4, 2022

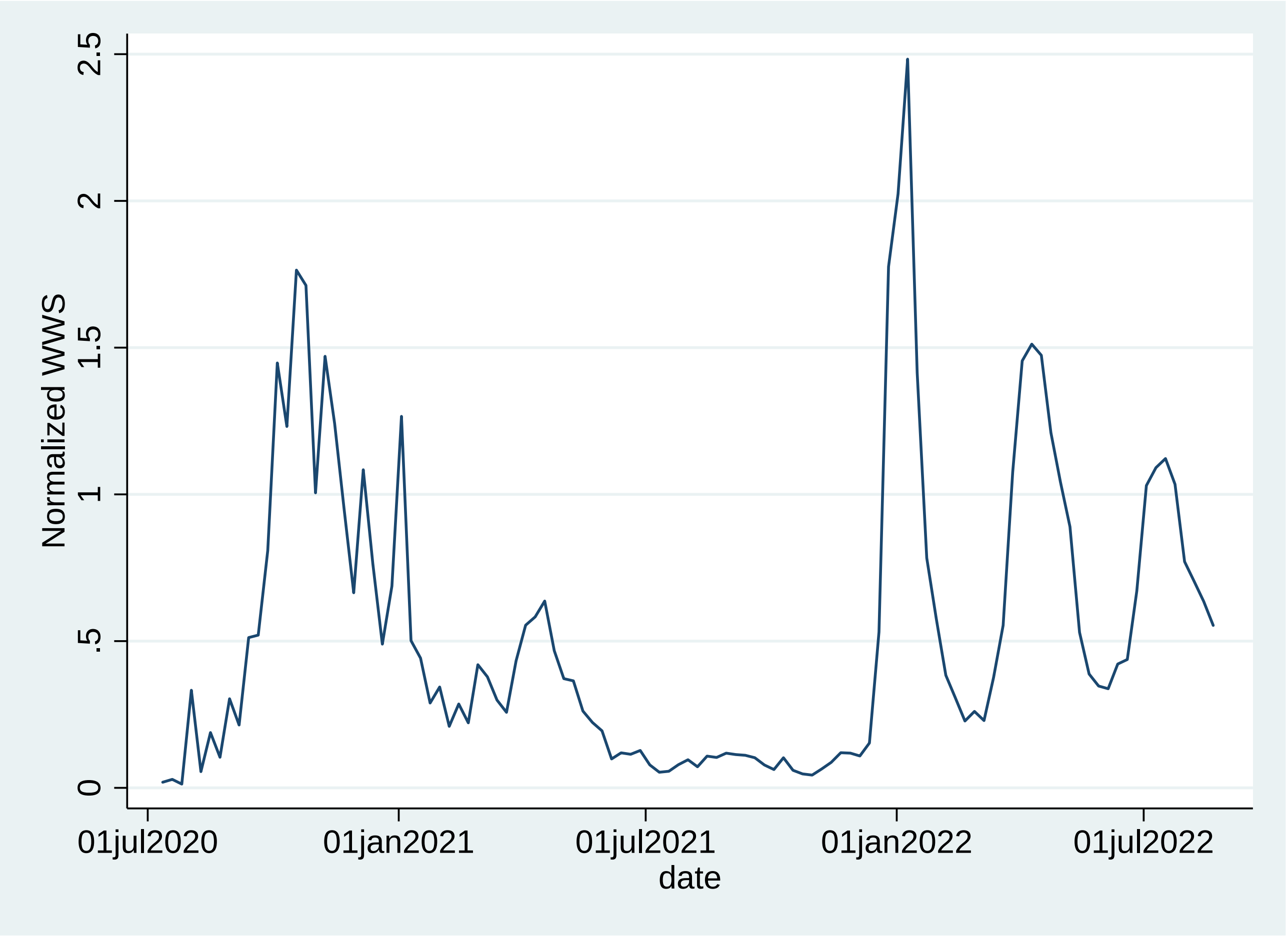
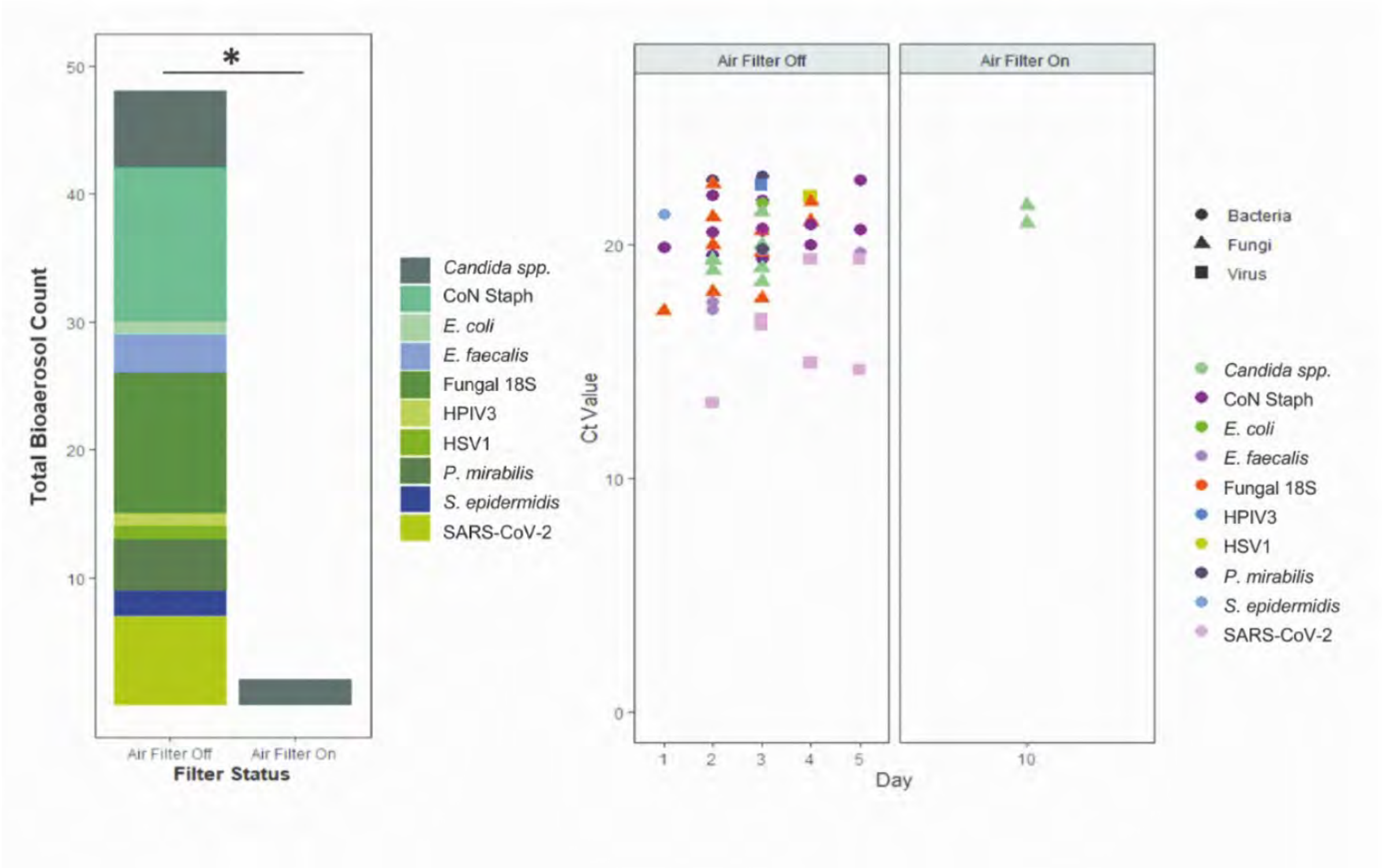


Figure 1. Bioaerosol detection in specific air sampler fractions over the 3-week testing period on a “surge” ward and ...



Clin Infect Dis, Volume 75, Issue 1, 1 July 2022, Pages e97–e101, https://doi.org/10.1093/cid/ciab933

OXFORD UNIVERSITY PRESS

Air Monitoring in Community Settings, Wisconsin/Minnesota, 2021-2022

Article

https://doi.org/10.1038/s41467-022-32406-w

SARS-CoV-2 and other respiratory pathogens are detected in continuous air samples from congregate settings

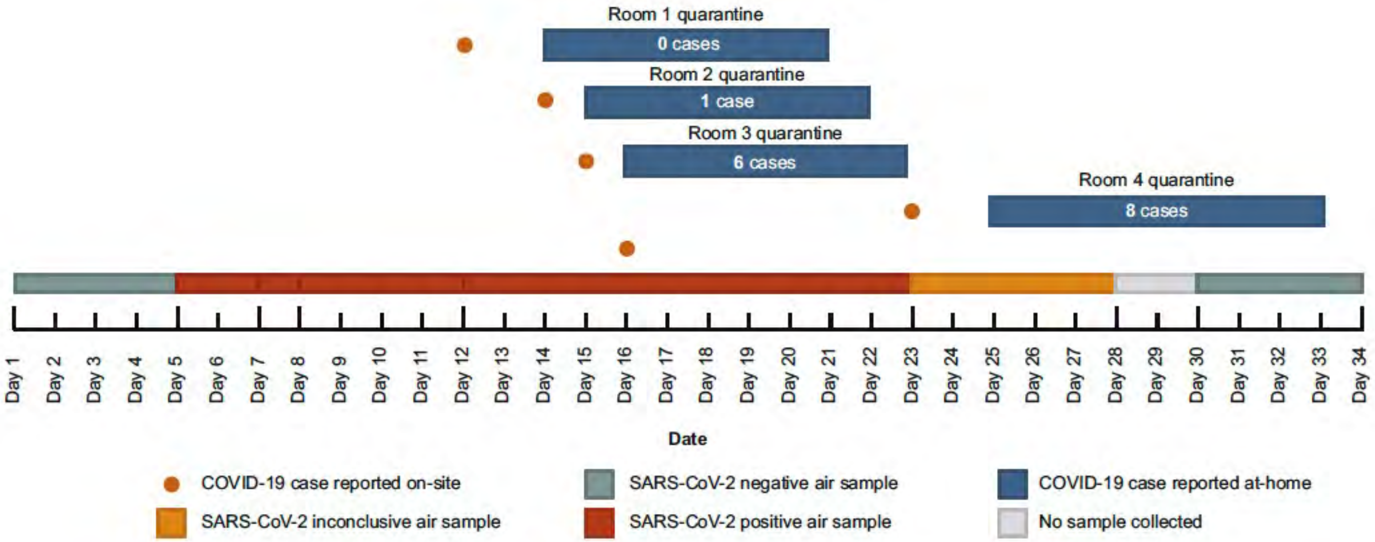
Received: 25 March 2022

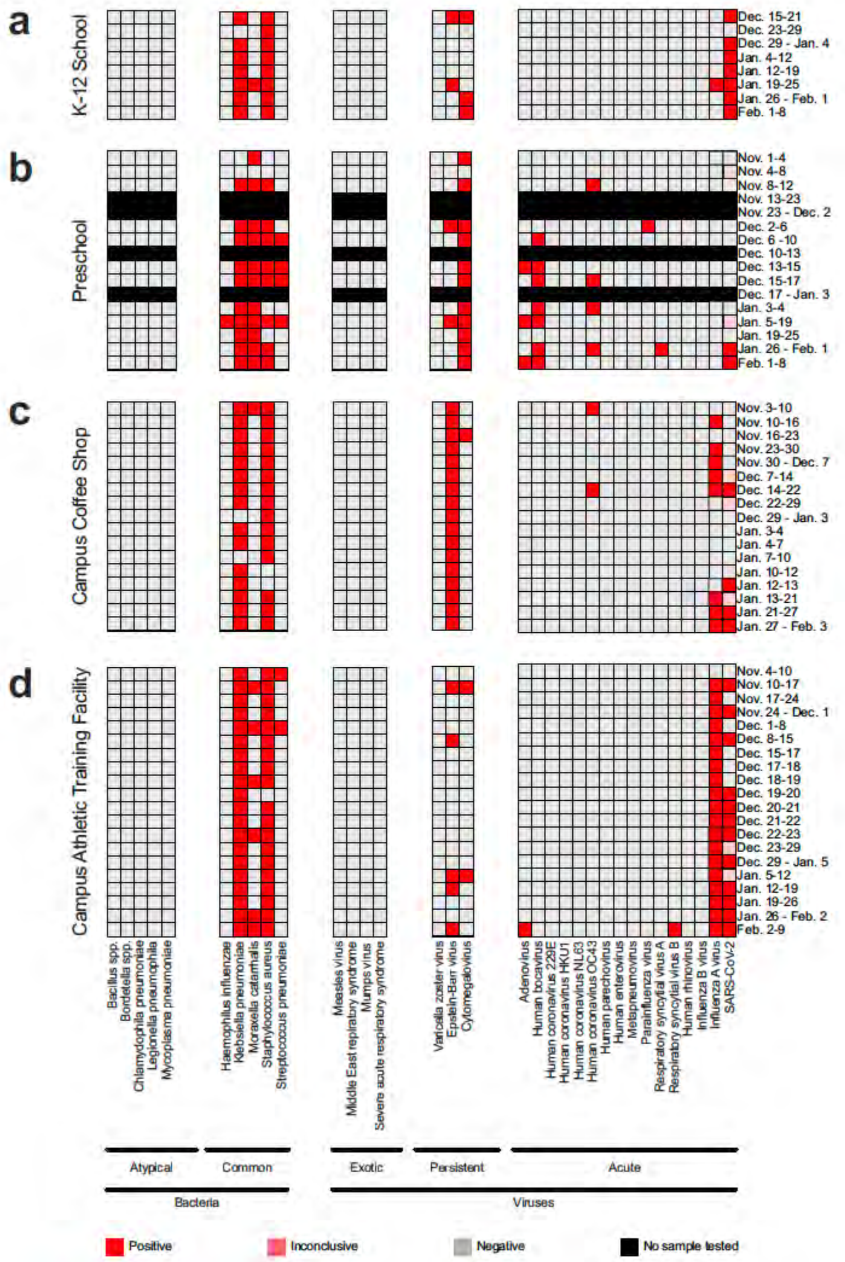
Accepted: 26 July 2022

Published online: 11 August 2022

Check for updates

Mitchell D. Ramuta[1], Christina M. Newman[1], Savannah F. Brakefield[1], Miranda R. Stauss[2], Roger W. Wiseman[1,2], Amanda Kita-Yarbro[3], Eli J. O'Connor[4], Neeti Dahal[5], Ailam Lim[5], Keith P. Poulsen[5], Nasia Safdar[6], John A. Marx[6], Molly A. Accola[6], William M. Rehrauer[1,6], Julia A. Zimmer[7], Manjeet Khubbar[7], Lucas J. Beversdorf[7], Emma C. Boehm[8], David Castañeda[8], Clayton Rushford[9], Devon A. Gregory[9], Joseph D. Yao[10], Sanjib Bhattacharyya[7], Marc C. Johnson[9], Matthew T. Aliota[8], Thomas C. Friedrich[11], David H. O'Connor[1,2,12] & Shelby L. O'Connor[1,2,12]



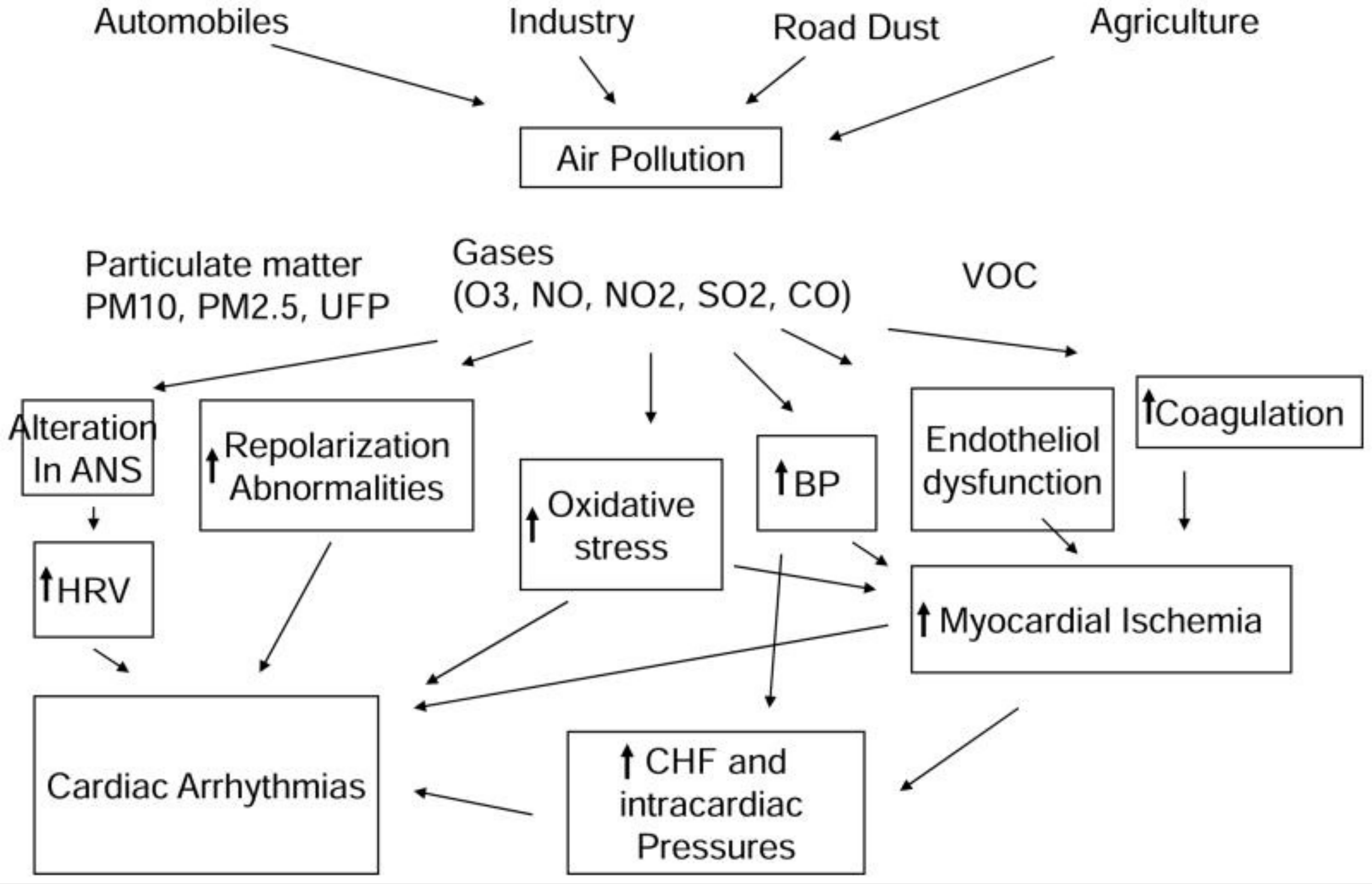


Ramuta et al., https://www.nature.com/articles/s41467-022-32406-w

Health Benefits of Clean Indoor Air

- Reduced transmission of infectious diseases but also:
  - Reduced exposure to indoor toxins: particulates, organic molecules, molds.
  - Benefits: asthma, cardiac disease and stroke, cognition, maybe even reduced dementia risk!
  - Improving indoor air = reducing class sizes!

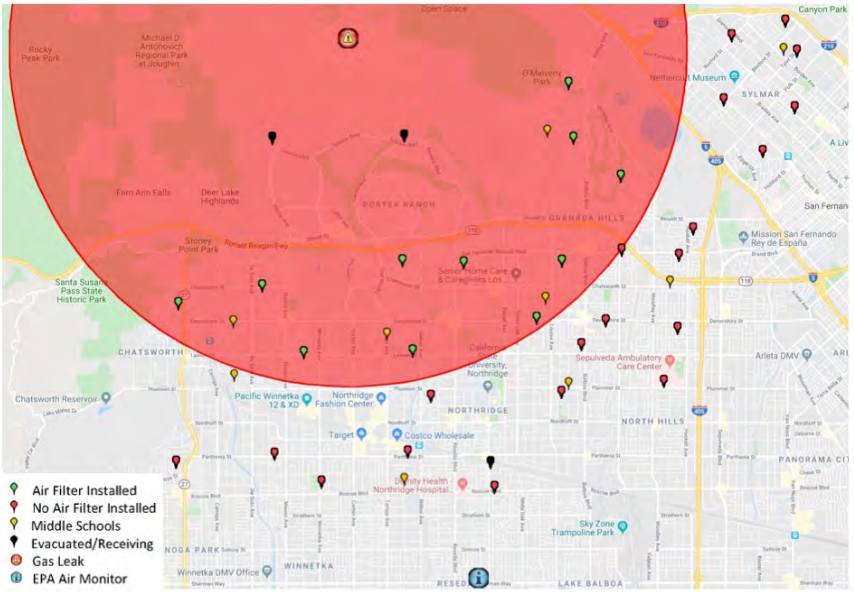
Air Pollutants and Cardiac Arrhythmias [Link and Dockery 2013]

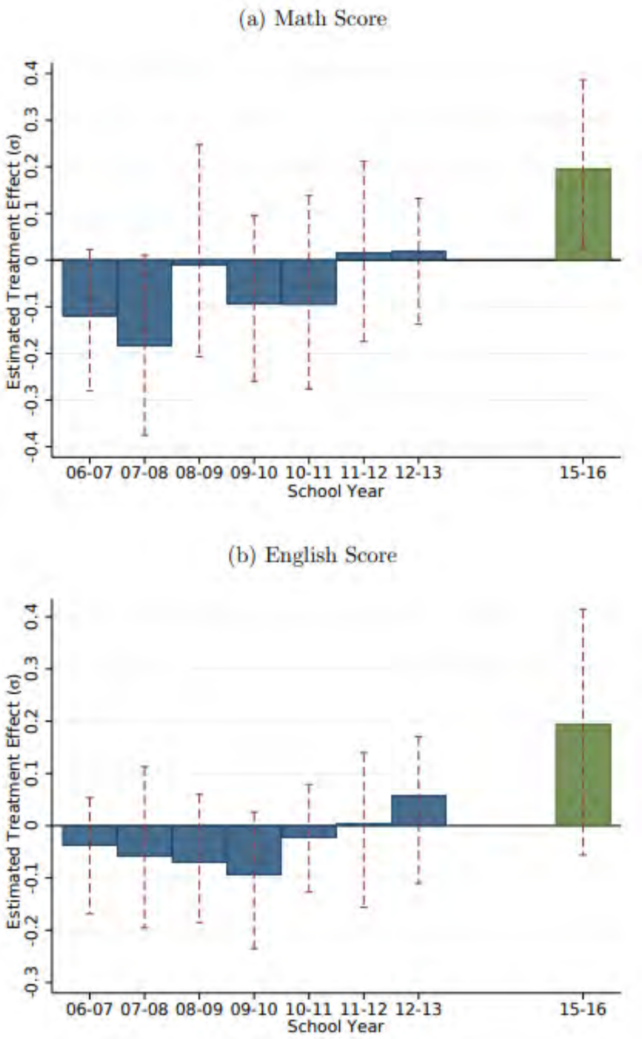


0.2 σ increase in test scores = 1/3 reduction in class size.

School Achievement and Indoor Air (Filters)

Figure 1: Map of Region of Interest



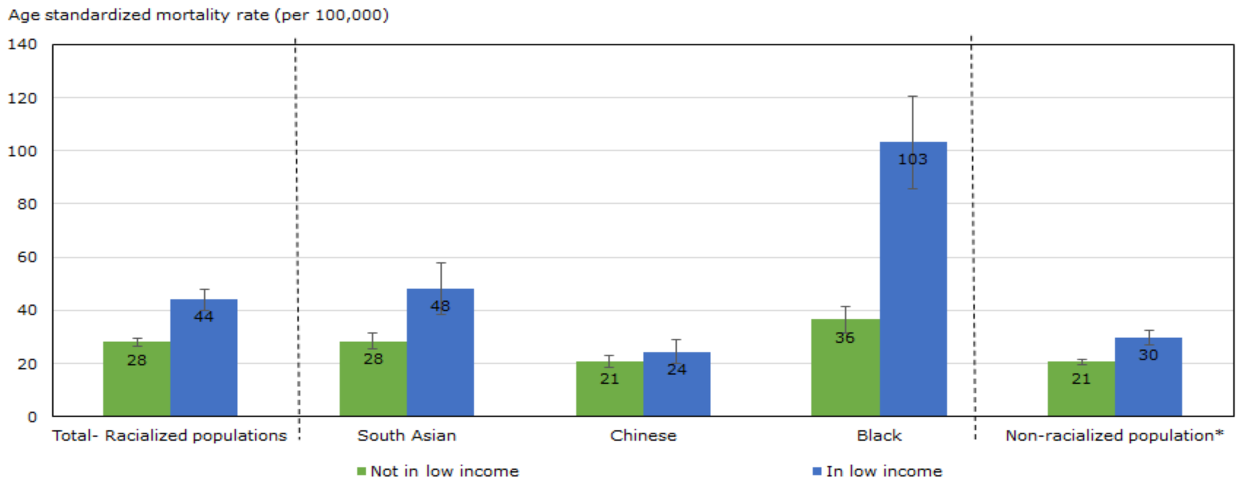


Michael Gilraine, NBER Working Paper. https://www.edworkingpapers.com/sites/default/files/Gilraine_AirFilters_1.pdf.

Clean Indoor Air and Infectious Diseases: A Health Equity Issue

Gupta and Aitken, https://www150.statcan.gc.ca/n1/pub/45-28-0001/2022001/article/00010-eng.htm

Chart 2
Age-standardized COVID-19 mortality rates in Canada between January 1, 2020 and December 31, 2020, by racialized groups and low income status (low-income measure (LIM) – after tax) in 2016



Note: *Non-racialized population excludes Indigenous people.
Source: Canadian Census Health and Environmental Cohort 2016 linked to Canadian Vital Statistics – Death Database from 2016-2020 (#3233).

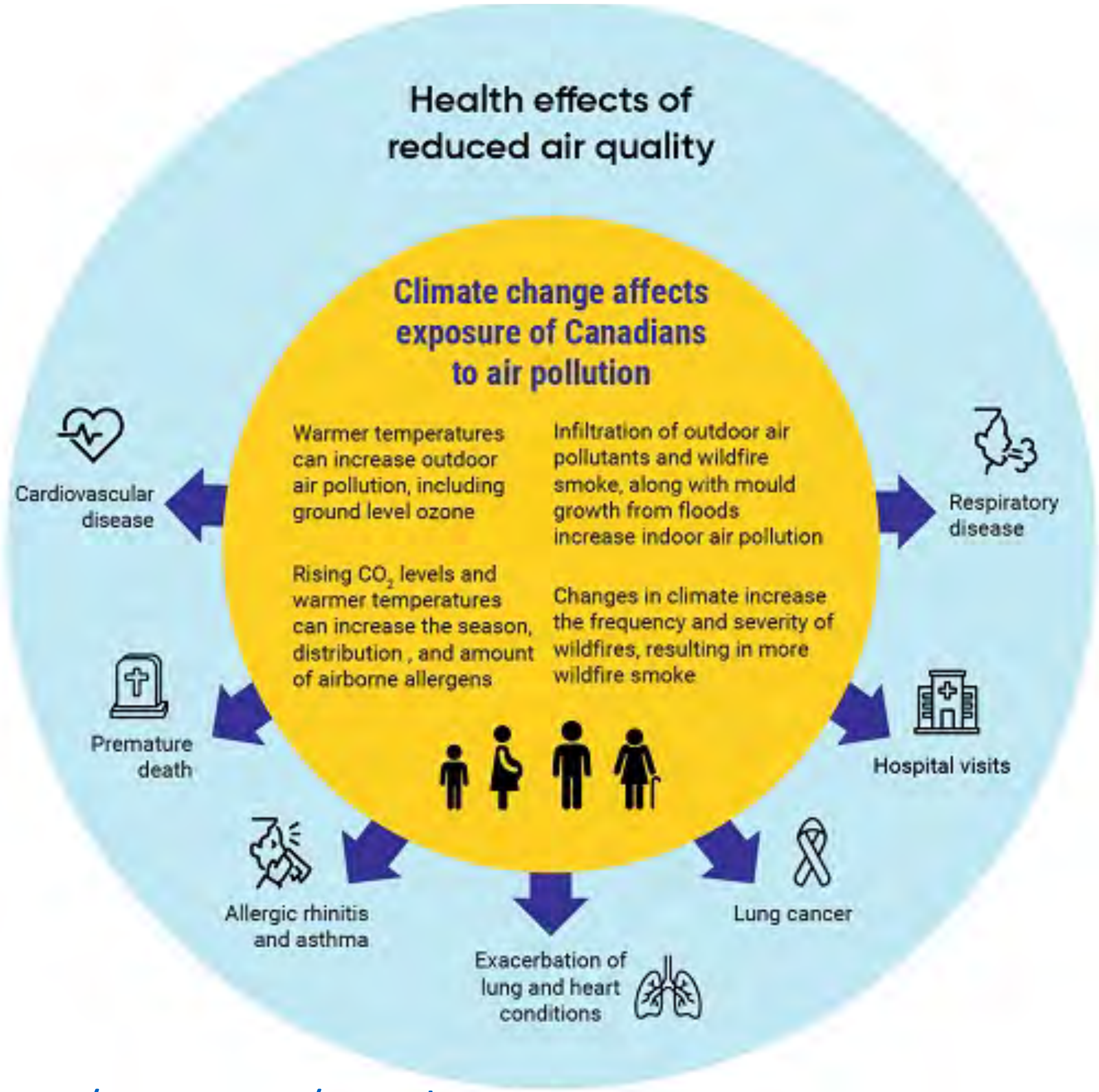
Table 1
Likelihood of dying from COVID-19 in 2020 by racialized populations, low income status (low income measure (LIM) – after tax) and other characteristics, Canada

Variable	Model 1				Model 2: Moderation			
	Odds Ratio	95% confidence interval		p-value	Odds Ratio	95% confidence interval		p-value
		from	to			from	to	
Sex								
Male versus Female	1.7	1.6	1.9	<.05	1.7	1.6	1.9	<.05
Age	1.1	1.1	1.1	<.05	1.1	1.1	1.1	<.05
Housing Suitability								
Not suitable housing versus suitable housing	1.5	1.3	1.9	<.05	1.5	1.2	1.9	<.05
Type of Dwelling								
Apartment versus house	2.1	1.9	2.3	<.05	2.1	1.9	2.3	<.05
Low Income Status After Tax								
In low income versus not in low income	1.3	1.1	1.4	<.05	1.3	1.1	1.4	<.05

Outdoor Air—Increasing Awareness of Health Effects

Environment Canada Estimates:

- 15,300 premature deaths
- 2.7 million asthma symptom days
- 35 million acute respiratory symptom days
- Economic costs of impacts of air pollution in Canada~ $120B per year.

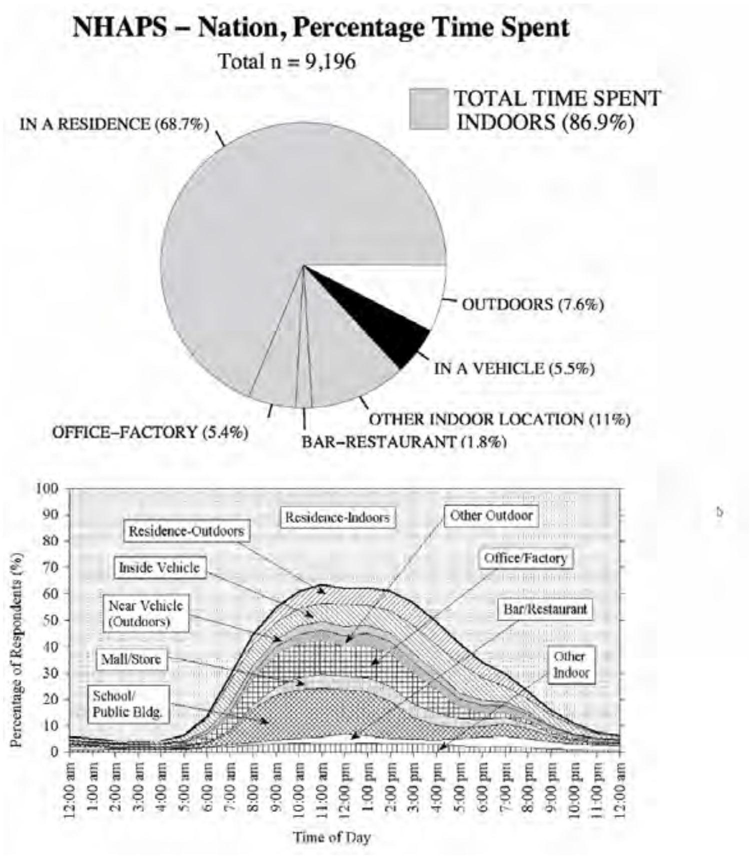


[Source: https://www.canada.ca/en/environment-climate-change/campaigns/canadian-environment-week/clean-air-day/health-impacts-air-pollution.html and https://www.canada.ca/en/health-canada/services/air-quality/outdoor-pollution-health.html#a1

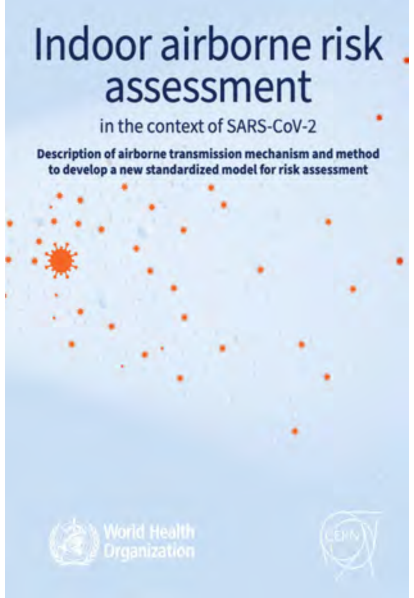
We Spend Most of Our Time Indoors

- US EPA: indoor air pollutant levels 2-5 x higher than outdoors.
- Can be as high as 100x higher in poorly ventilated spaces.
- People spend ~ 90% of time indoors.

- Figure and data courtesy of Prof. Kim Prather.



Exciting Recent Developments (since May 2023)



How Much Ventilation Is Enough?

Aim for 5 Air Changes per Hour (ACH)

When possible, aim for 5 or more air changes per hour (ACH) of clean air to help reduce the number of germs in the air.

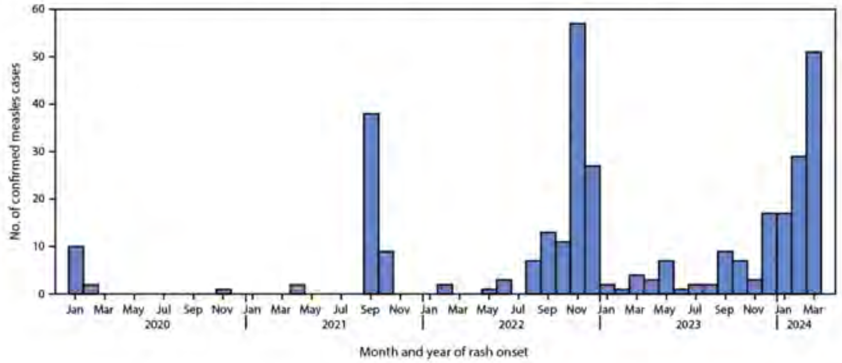
This can be achieved through any combination of central ventilation system, natural ventilation, or additional devices that provide equivalent ACH (eACH[i]) to your existing ventilation. Supplying or exhausting an amount of air (use the larger of the two values but do not add them together) that is equal to all the air in a space is called an air change. Multiplying that amount by 5 and delivering it over one hour results in 5 ACH.

- Resources: https://www.ashrae.org/technical-resources/bookstore/ashrae-standard-241-control-of-infectious-aerosols; https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html#:~:text=Aim%20for%205%20Air%20Changes,of%20germs%20in%20the%20air; https://iris.who.int/bitstream/handle/10665/376346/9789240090576-eng.pdf?sequence=1&isAllowed=y; https://arpa-h.gov/news-and-events/arpa-h-launches-breathe-monitor-and-improve-indoor-air-quality

Measles Resurgence and Simple Models of Herd Immunity

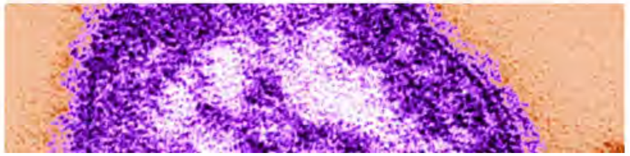
What Happens in Las Vegas…

FIGURE. Confirmed measles cases, by month of rash onset (N = 338) — United States, January 1, 2020–March 28, 2024



LOCAL NEWS

Out-of-state visitor diagnosed with measles, possibly exposed those on Las Vegas Strip



Factors Driving Disease Emergence

- **How** do diseases emerge and spread?
  - Need a “seed” (novel pathogen, opportunity for human infection).
  - Need “soil” (environmental conditions for introduction, ongoing reintroduction, or person-to-person transmission).
  - We describe this as a reproduction number (R).
    - R can be < 1 (clusters) or > 1 (outbreaks and epidemics).

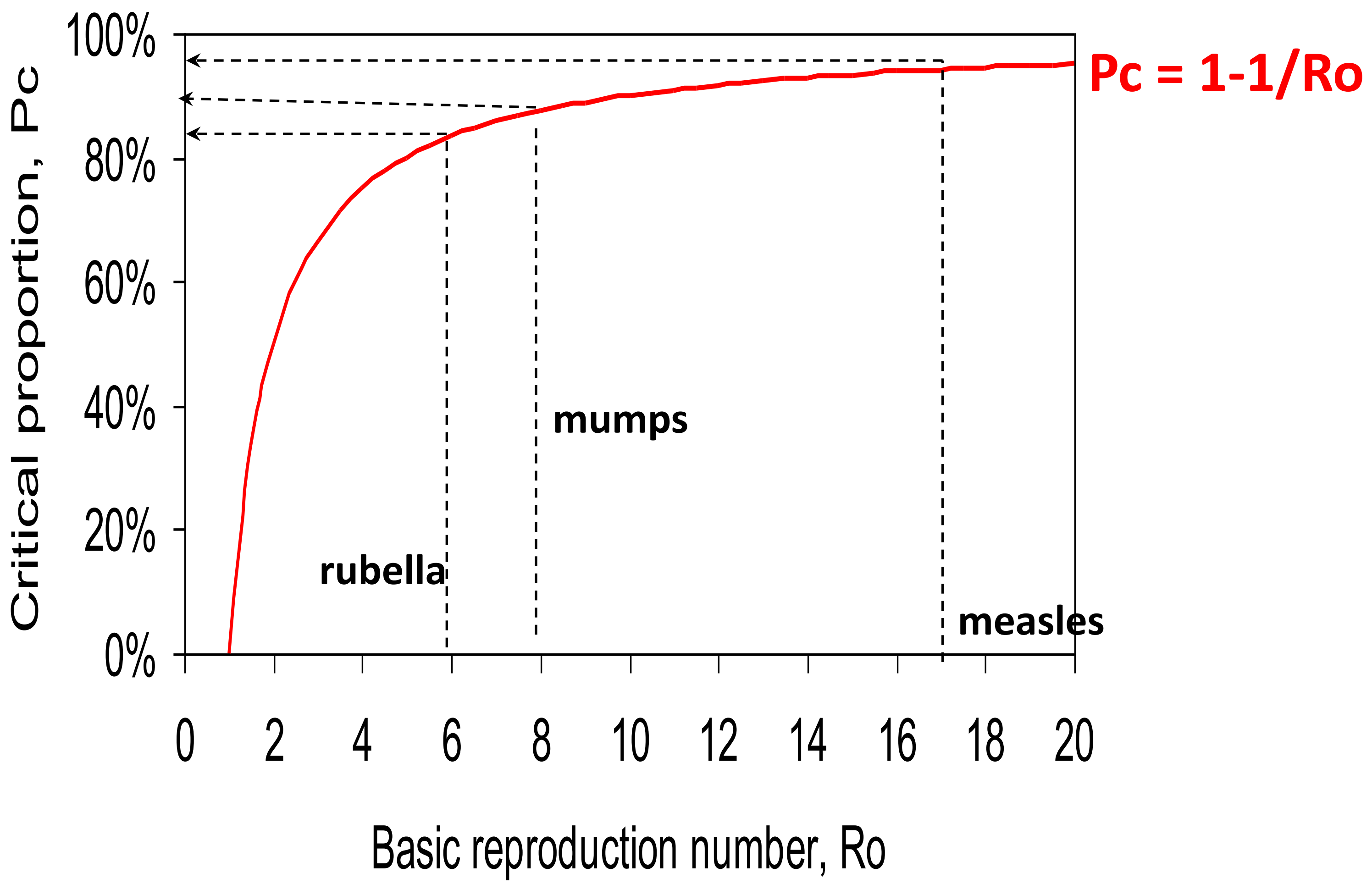
Further Elaboration: R_e

- Once a disease process is recognized, control activities and behavioral change may impact p, c, and D.
- Recovered individuals may also become immune.
- The R in this situation is often called “effective R” (R_e) or “R at some time(t)” (R_t).

$R_e = p' \times c' \times D' \times S$

- **S** is the fraction of susceptible individuals in the population.
- **S*** is the **critical fraction** of susceptibles needed for Re = 1.
- **$S^* = 1/R_0$** (!!)
- Critical fraction to vaccinate (P_c) is just 1-S*, so $P_c = 1-1/R_0$.

Coverage Required for Elimination



Time for a Little Game Theory…

- Ref: Chris Bauch and David Earn, PNAS 2004. https://www.pnas.org/doi/full/10.1073/pnas.0403823101#:~:text=Description%20of%20Game.&text=We%20ignore%20any%20delay%20between,to%20the%20vaccine%20uptake%20level.

RESEARCH ARTICLE | APPLIED MATHEMATICS

Vaccination and the theory of games

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Abstract

Voluntary vaccination policies for childhood diseases present parents with a subtle challenge: if a sufficient proportion of the population is already immune, either naturally or by vaccination, then even the slightest risk associated with vaccination will outweigh the risk from infection. As a result, individual self-interest might preclude complete eradication of a vaccine-preventable disease. We show that a formal game theoretical analysis of this problem leads to new insights that help to explain human decision-making with respect to vaccination. Increases in perceived vaccine risk will tend to induce larger declines in vaccine uptake for pathogens that cause more secondary infections (such as measles and pertussis). After a vaccine scare, even if perceived vaccine risk is greatly reduced, it will be relatively difficult to restore prescare vaccine coverage levels.

QUESTIONS?

"Did you switch conditioners?"