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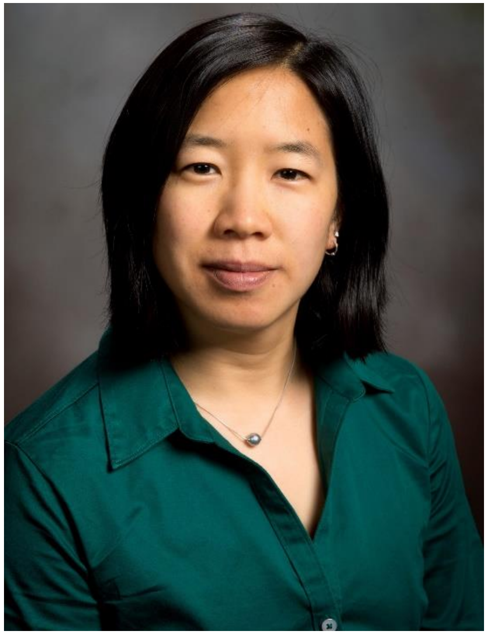
TODAY’S WEBINAR:

TRANSMISSION OF VIRUSES IN DROPLETS & AEROSOLS IN THE BUILT ENVIRONMENT



Presenter:
Linsey Marr, Ph.D.

Moderator: Kevin Brown, EI, A.M.ASCE

Transmission of Viruses in Droplets and Aerosols in the Built Environment

LINSEY C. MARR
CHARLES P. LUNSFORD PROFESSOR
CIVIL AND ENVIRONMENTAL ENGINEERING
VIRGINIA TECH

17 APRIL 2020

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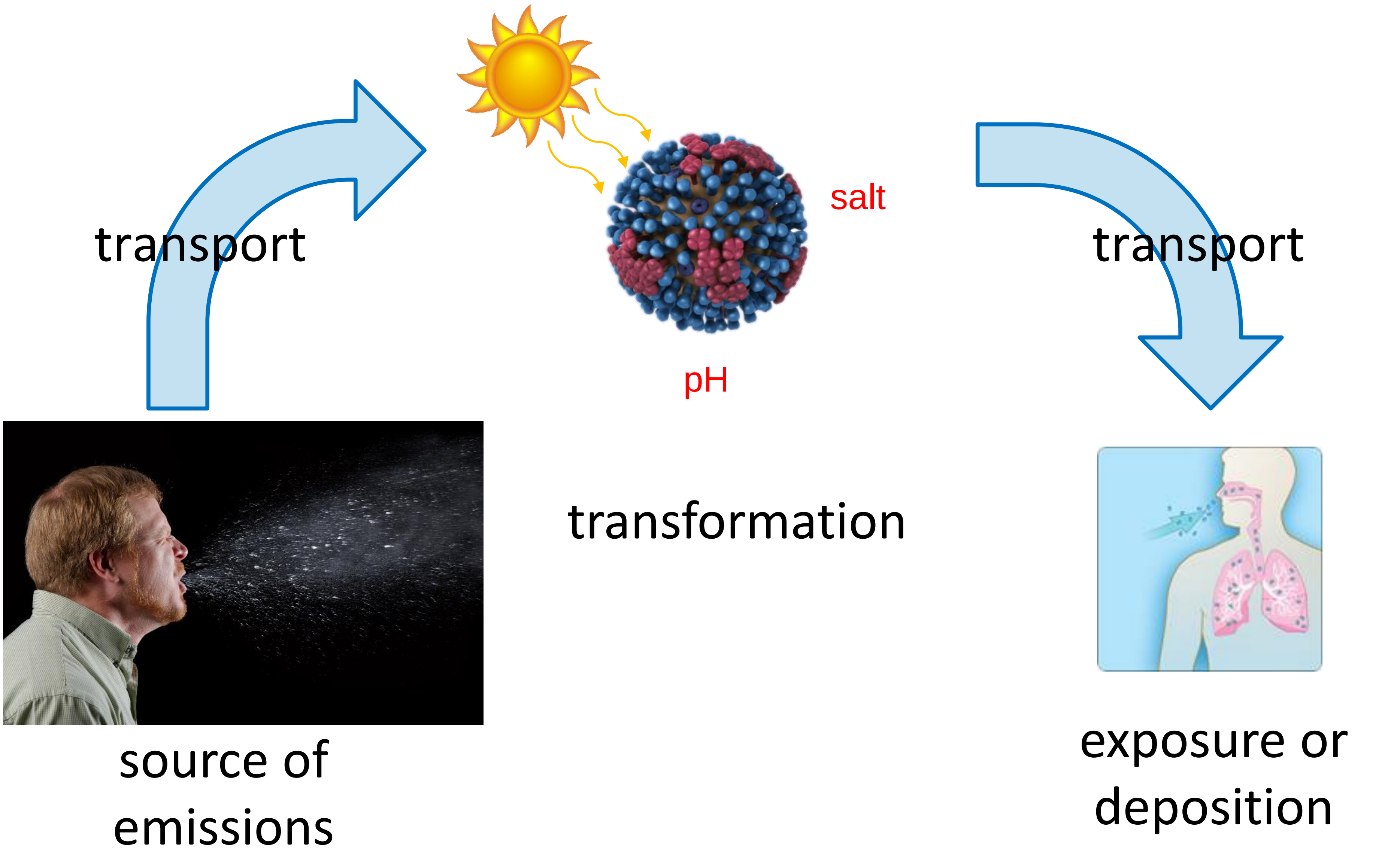
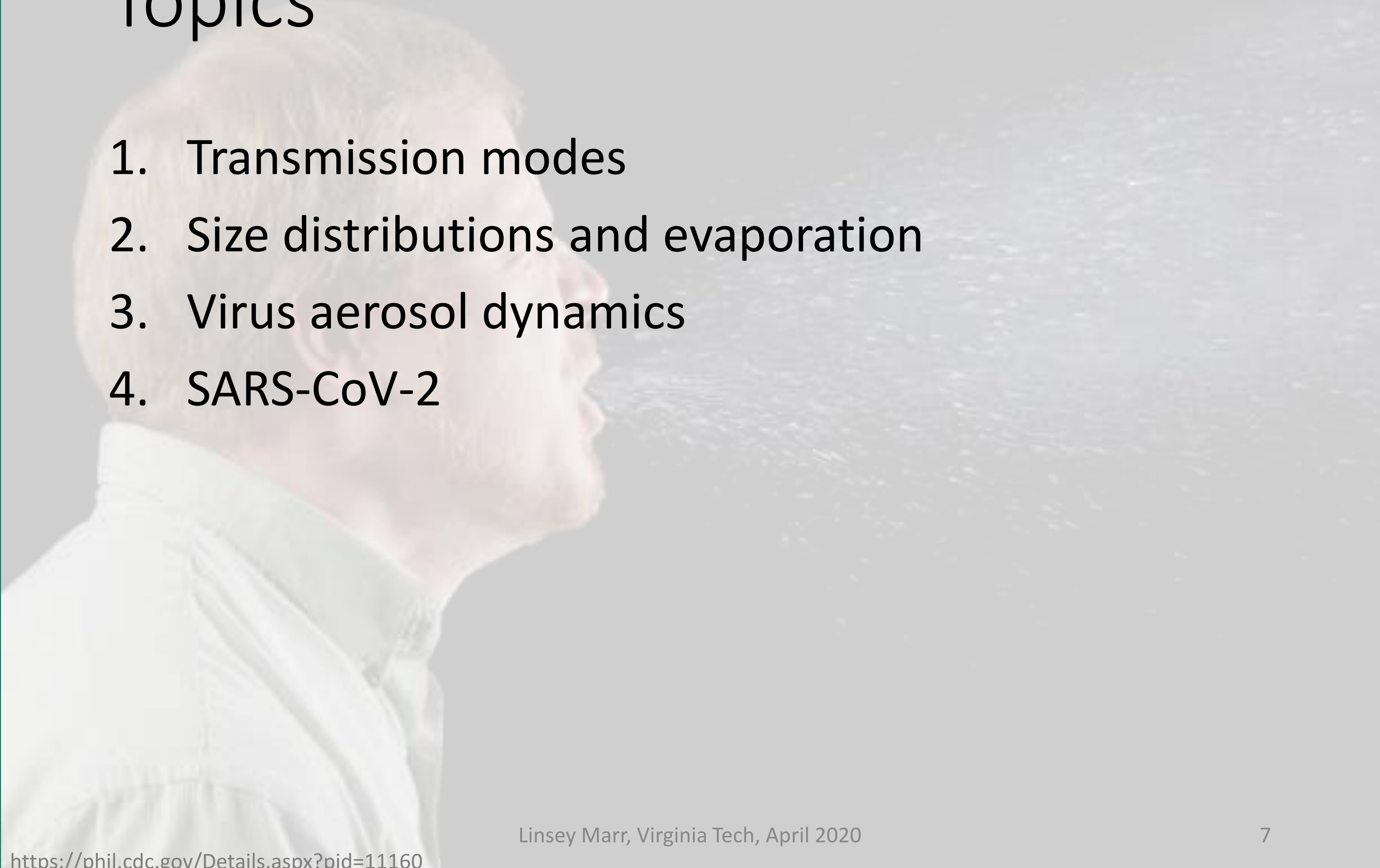

transport
salt
pH
transport
transformation
source of emissions
exposure or deposition

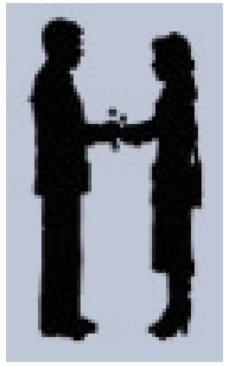
Topics

1. Transmission modes
2. Size distributions and evaporation
3. Virus aerosol dynamics
4. SARS-CoV-2

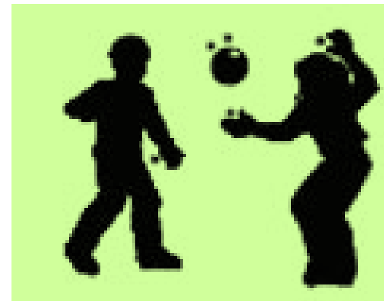


https://phil.cdc.gov/Details.aspx?pid=11160

Modes of Transmission

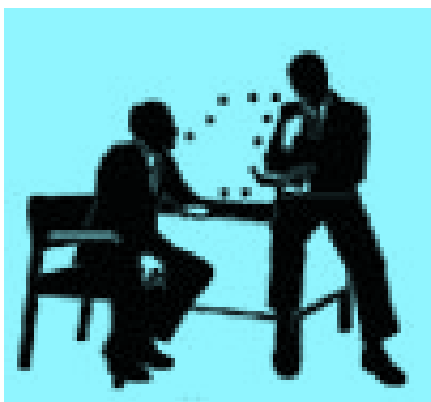


direct contact

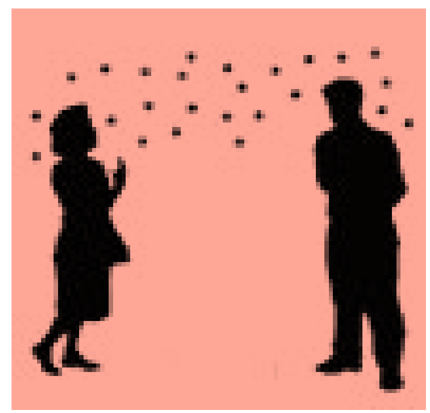


indirect contact

Defined as >5 µm and happening at close-range only (<2 m)



large droplets



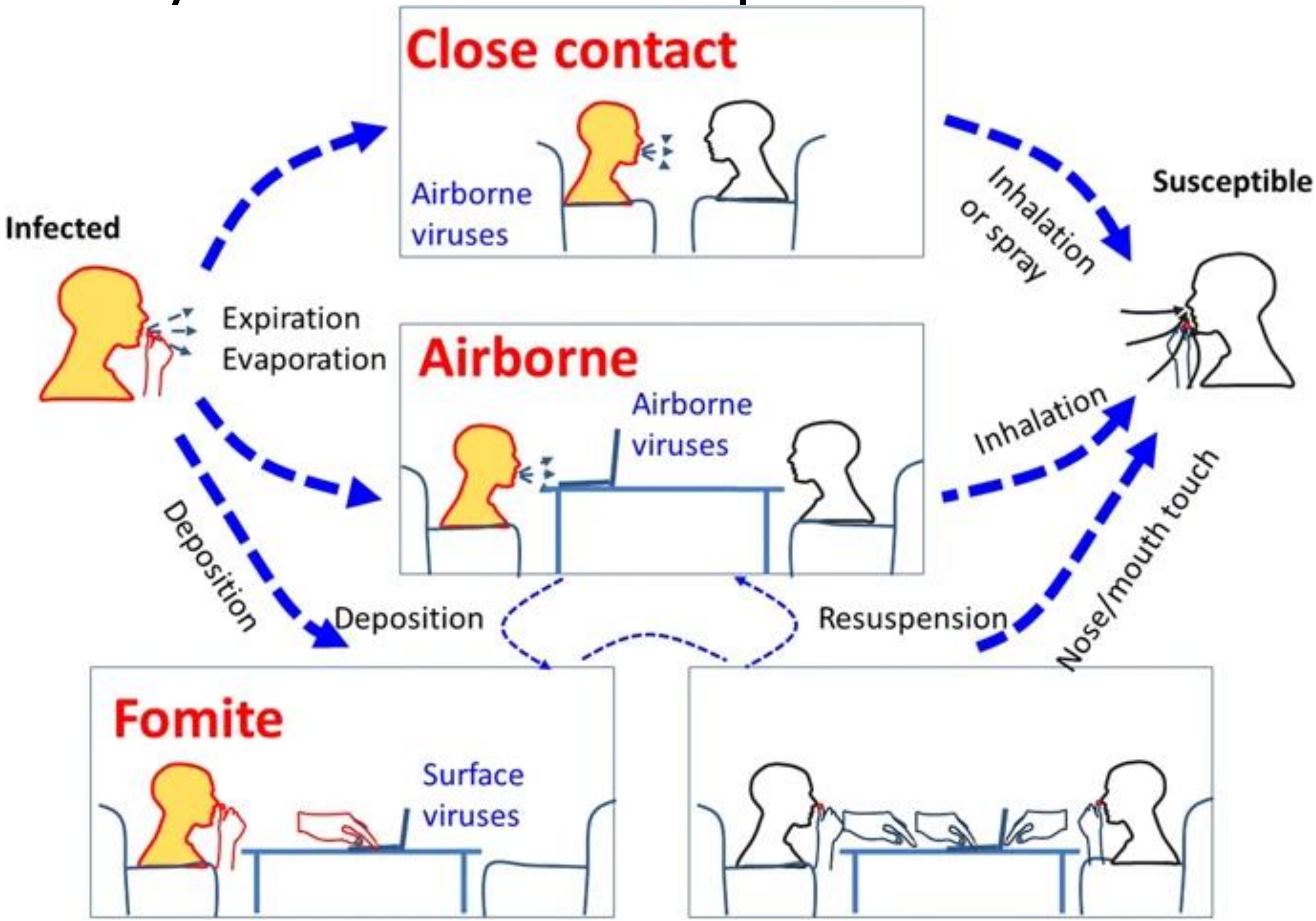
aerosols

Defined as <5 µm and happening mainly at long-distance (>2 m)

The origin of the 5-µm cutoff is not known. This cutoff is not supported by modern aerosol science. This distinction has hampered our understanding of transmission.

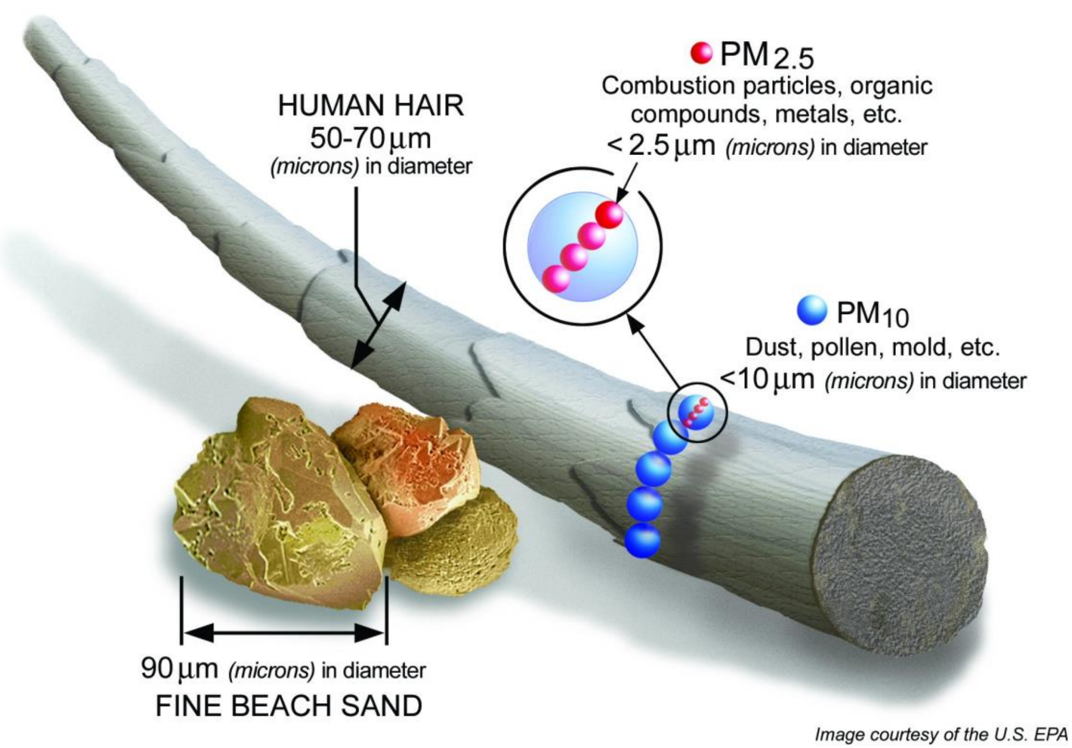
http://www.phac-aspc.gc.ca/cpip-pclcpi/annf/v2-eng.php

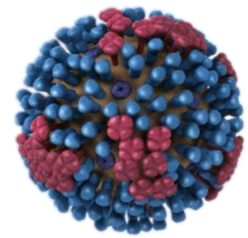
Reality is More Complicated



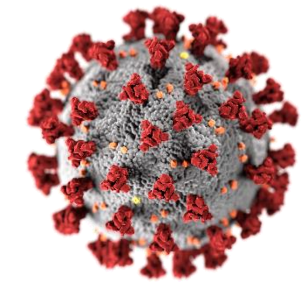
Tellier et al., 2019, *BMC Infect. Dis*, https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-019-3707-y

Virus Size

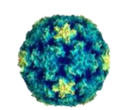




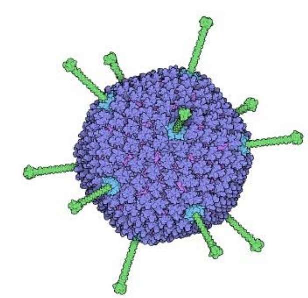
influenza
0.1 μm



SARS-CoV-2
0.12 μm



rhinovirus
0.03 μm

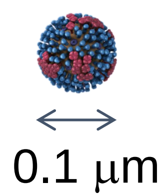


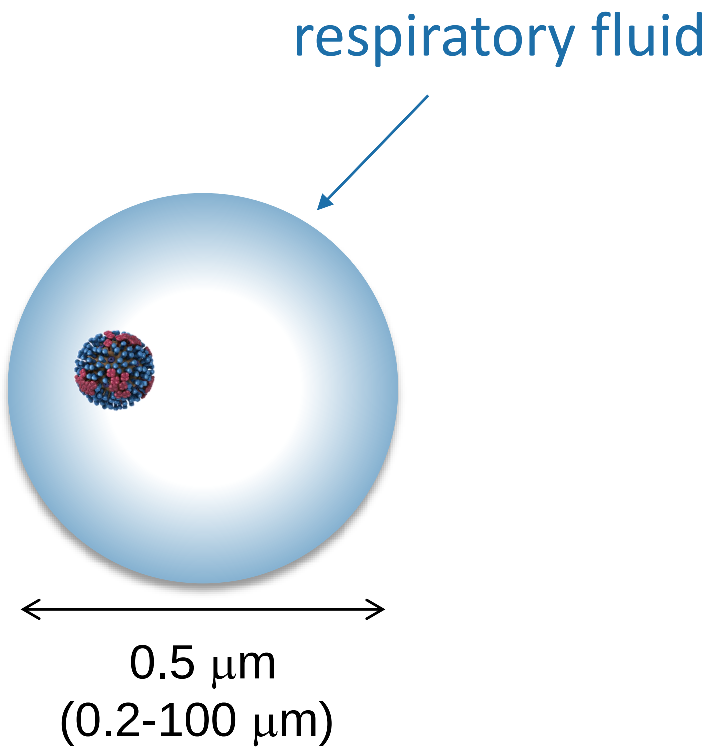
adenovirus
0.1 μm

https://www.cdc.gov/flu/resource-center/freeresources/graphics/images.htm, https://solutionsdesignedforhealthcare.com/rhinovirus, https://phil.cdc.gov/Details.aspx?pid=23312, https://pdb101.rcsb.org/motm/132

Size Matters

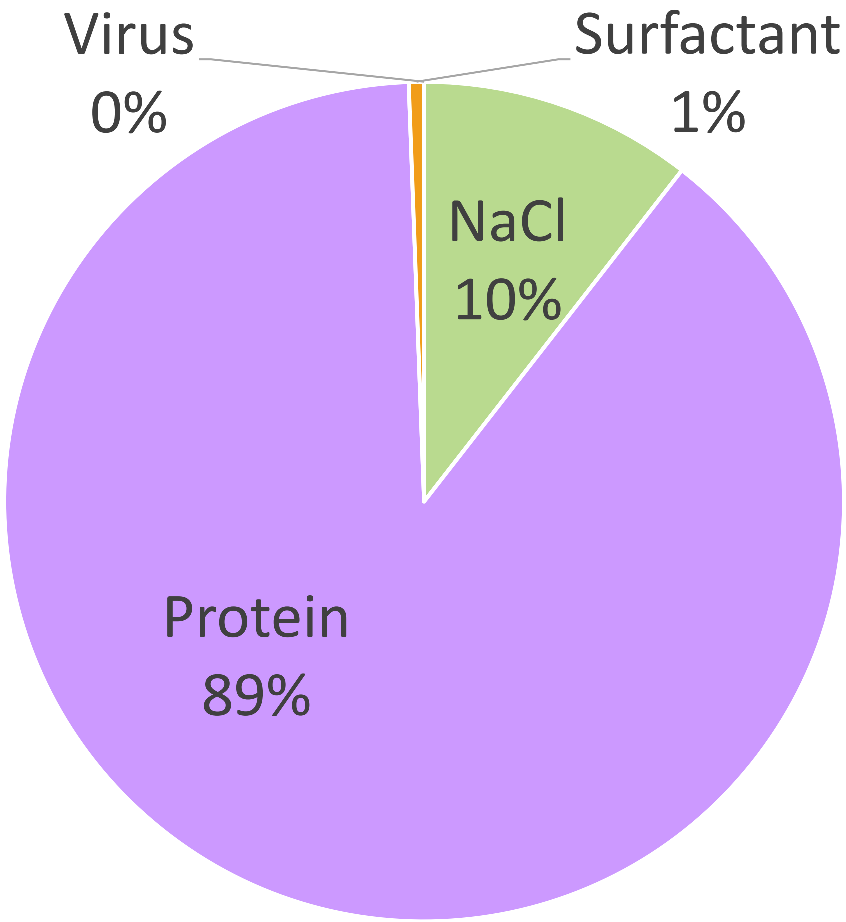
- Airborne virus is not naked!





- Size determines
  - Lifetime in the atmosphere
  - Where it deposits in the respiratory system

Droplet Composition by Mass



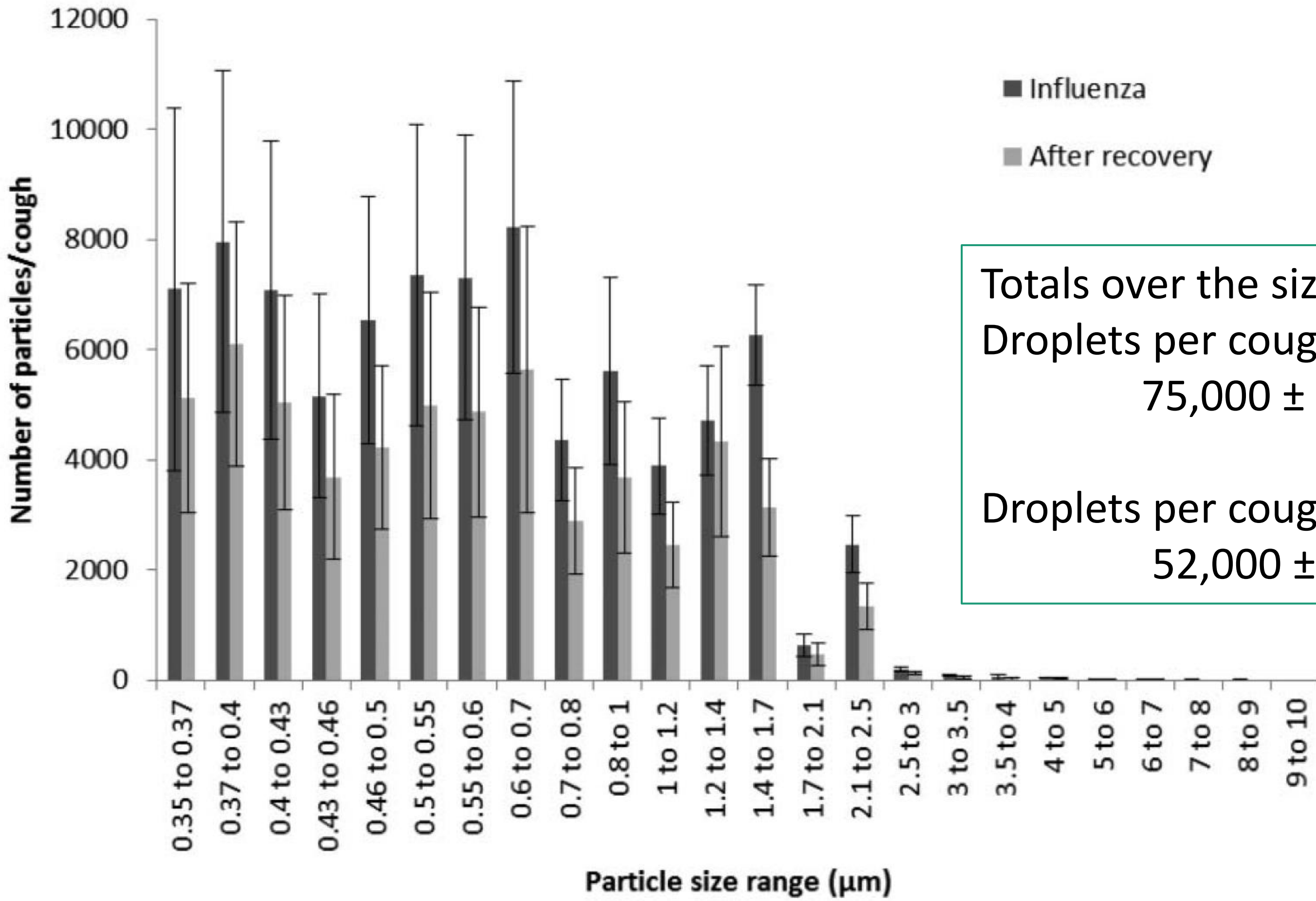
Non-volatiles are ~10% of initial mass (before evaporation)

Vejerano and Marr, 2018, *J. Roy. Soc. Interface*, https://royalsocietypublishing.org/doi/full/10.1098/rsif.2017.0939

Droplets that are expelled into air can be inhaled, land on people's mucus membranes, or deposit onto surfaces, where someone can touch them or they can be resuspended into air.

How many droplets are there, and how big or small are they?

Number of Droplets Emitted

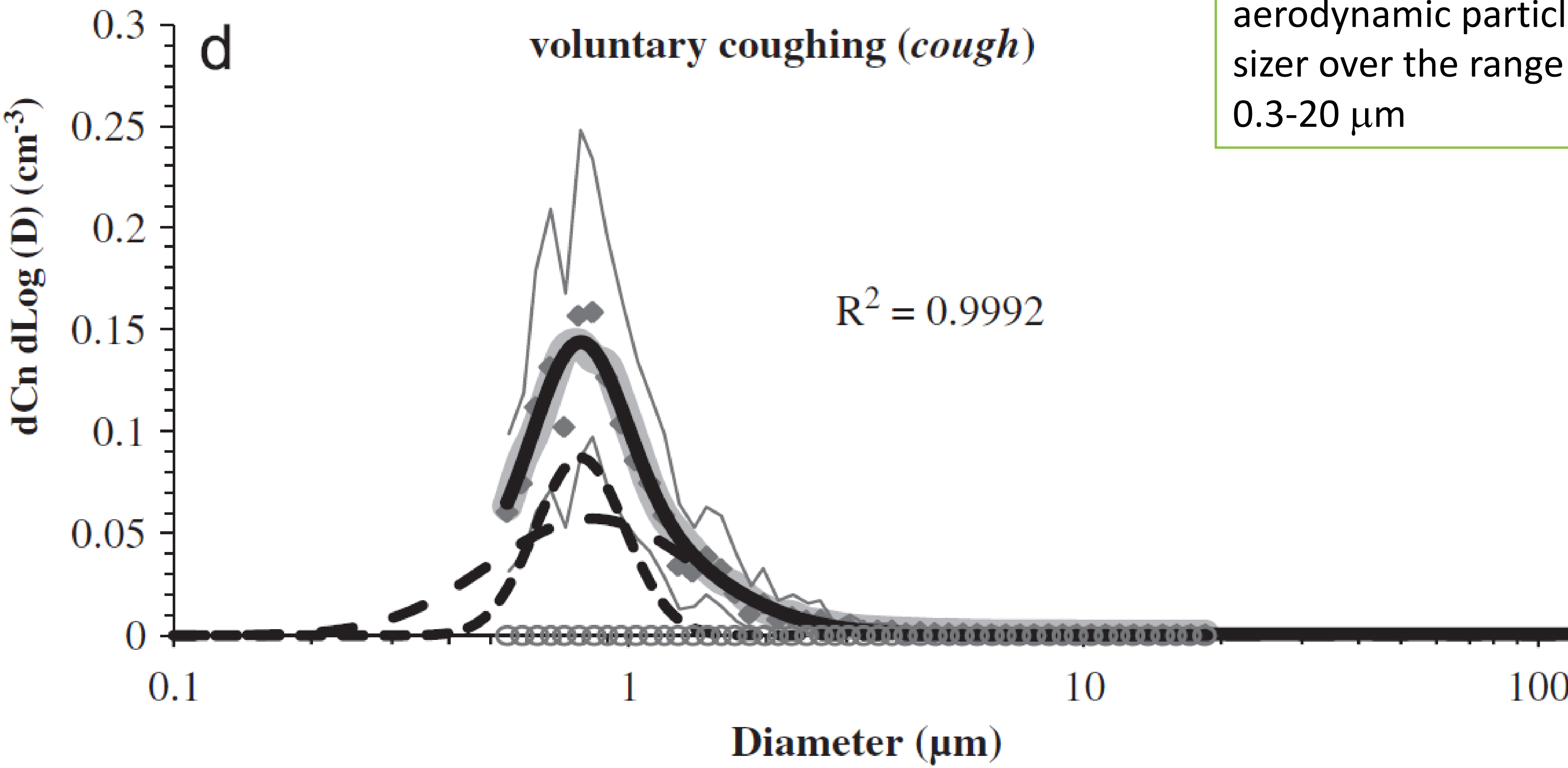


Totals over the size range <u>0.35-10 µm</u>:
Droplets per cough when sick
75,000 ± 97,000

Droplets per cough after recovery
52,000 ± 99,000

Lindsley et al., 2012, *J. Occupat. Environ. Hyg.*, https://www.ncbi.nlm.nih.gov/pubmed/22651099

Size Distributions: Coughing

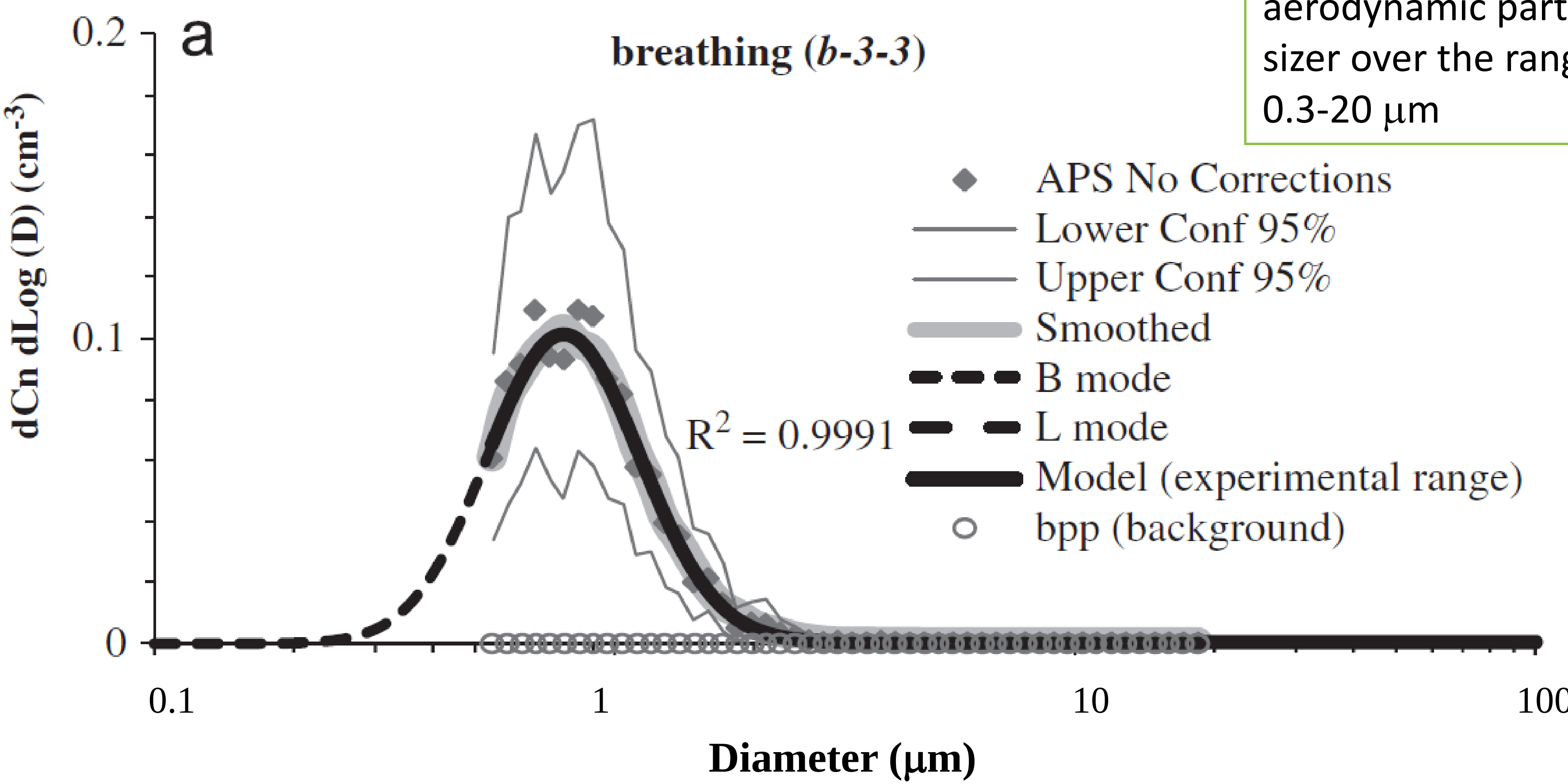


Measured by aerodynamic particle sizer over the range 0.3-20 μm

Johnson et al., 2011, *J. Aerosol Sci.*, https://www.sciencedirect.com/science/article/pii/S0021850211001200

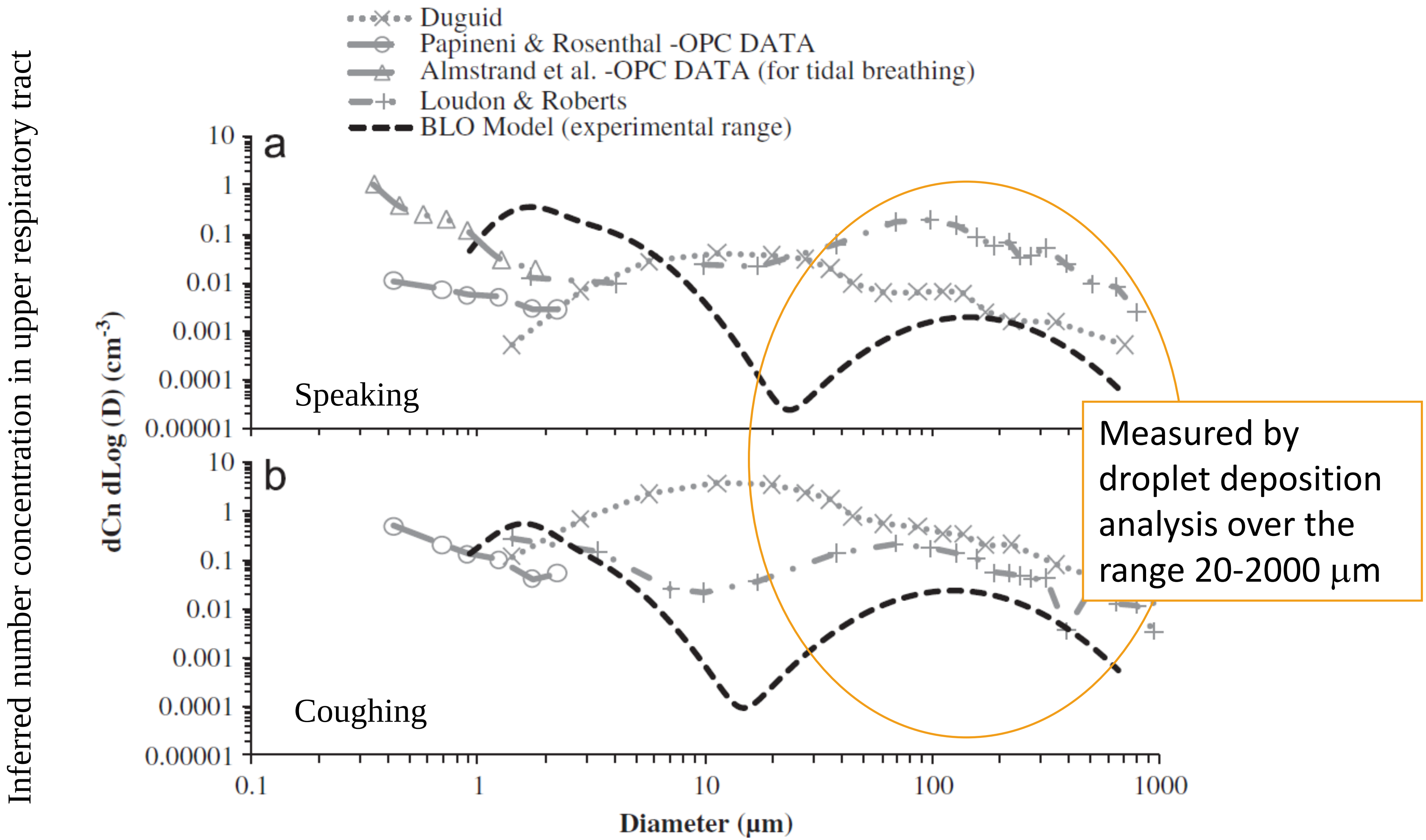
Size Distributions: Breathing

Measured by aerodynamic particle sizer over the range 0.3-20 μm



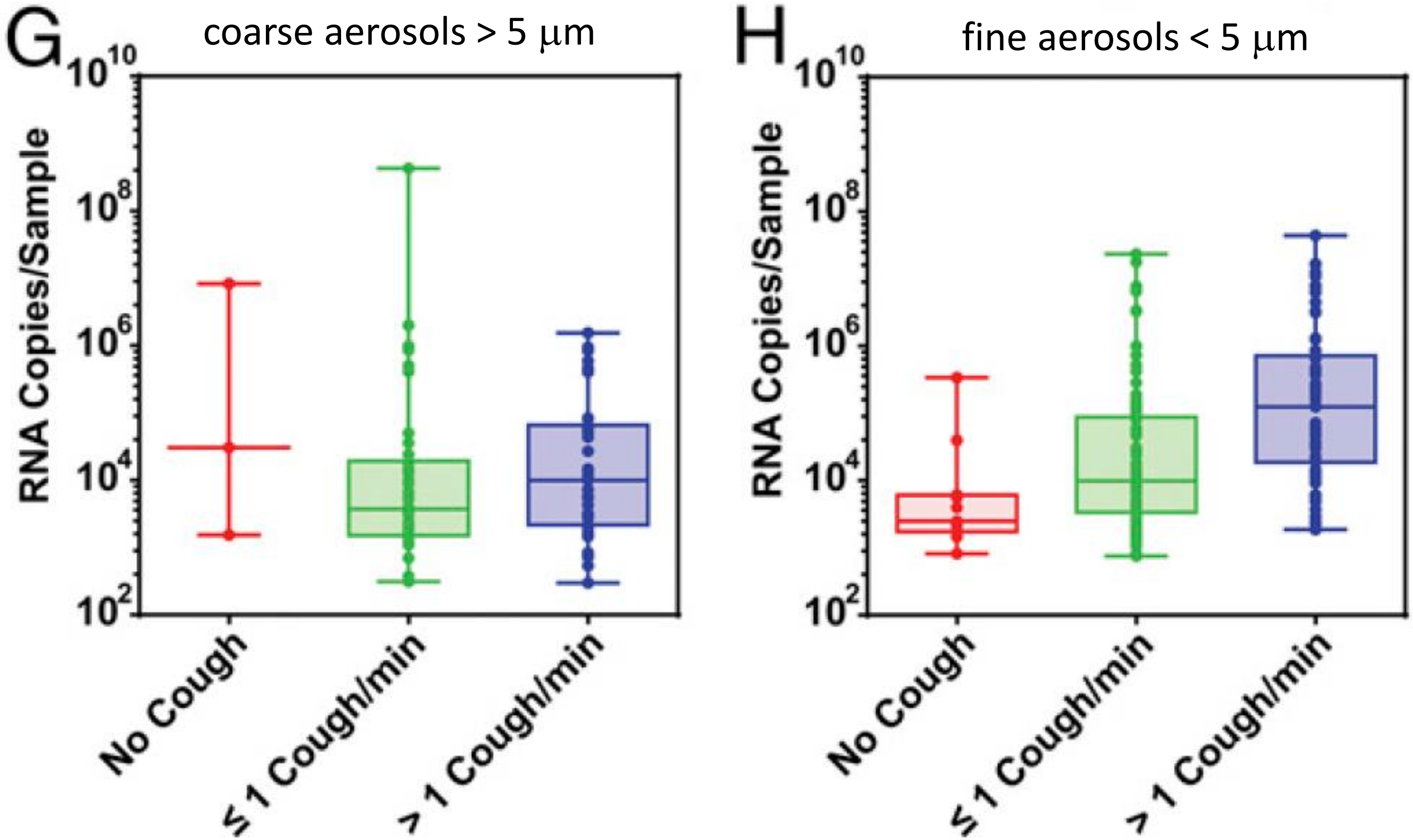
Johnson et al., 2011, *J. Aerosol Sci.*, https://www.sciencedirect.com/science/article/pii/S0021850211001200

Corrected Size Distributions



Johnson et al., 2011, *J. Aerosol Sci.*, https://www.sciencedirect.com/science/article/pii/S0021850211001200

Flu Virus in Droplets (Aerosols)



30-min sample
recite alphabet at 5, 15, 25 min

Yan et al., 2018, *PNAS*, https://www.ncbi.nlm.nih.gov/pubmed/29348203

Breathing, talking, and coughing release droplets that range from submicron to millimeter in size. The majority of flu virus in airborne droplets resides in the fine fraction and can be released by breathing and talking, without coughing.

How do these droplets move around the indoor environment?

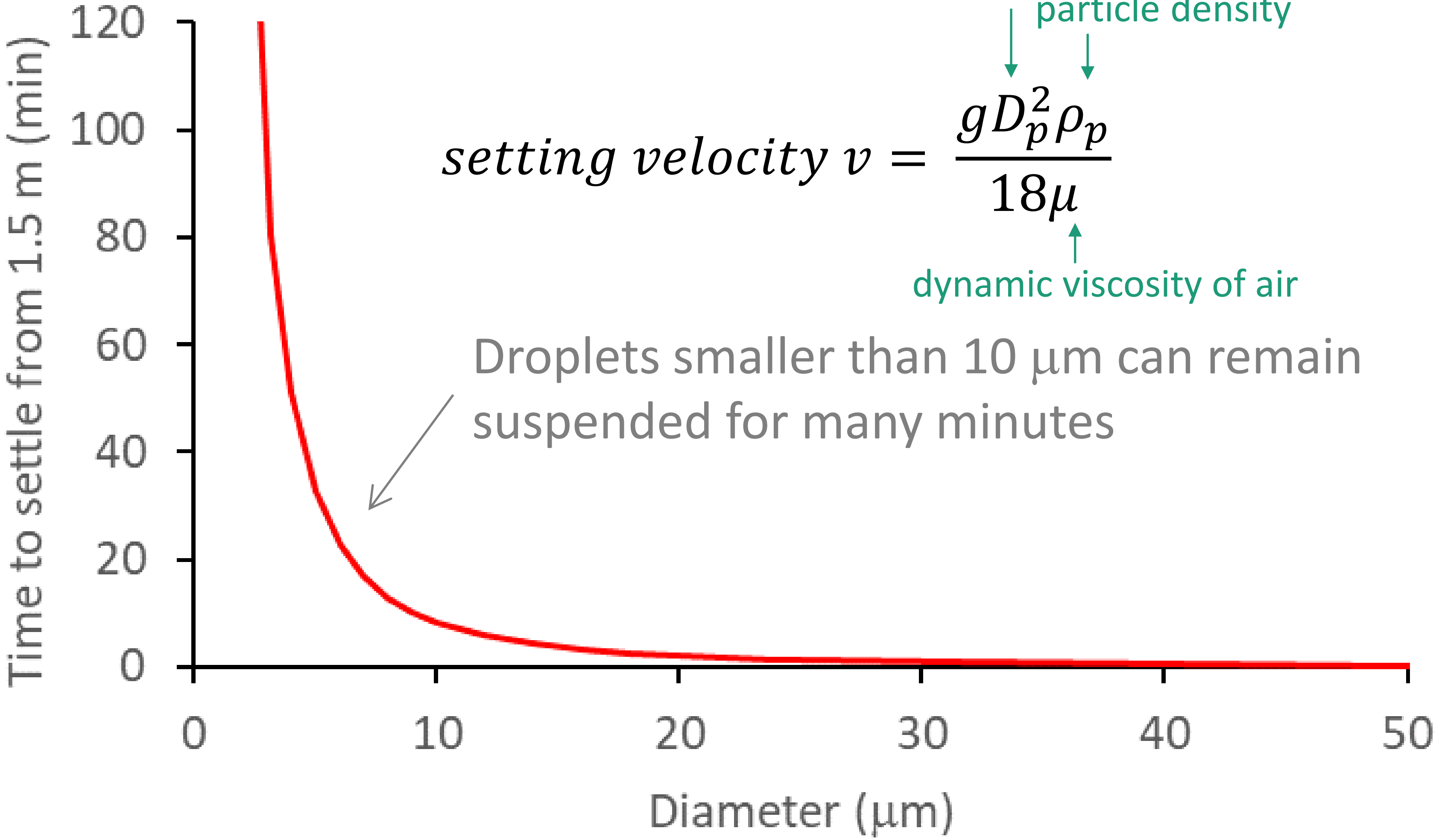
Settling Velocity and Time

particle diameter

particle density

$$setting\ velocity\ v = \frac{gD_p^2\rho_p}{18\mu}$$

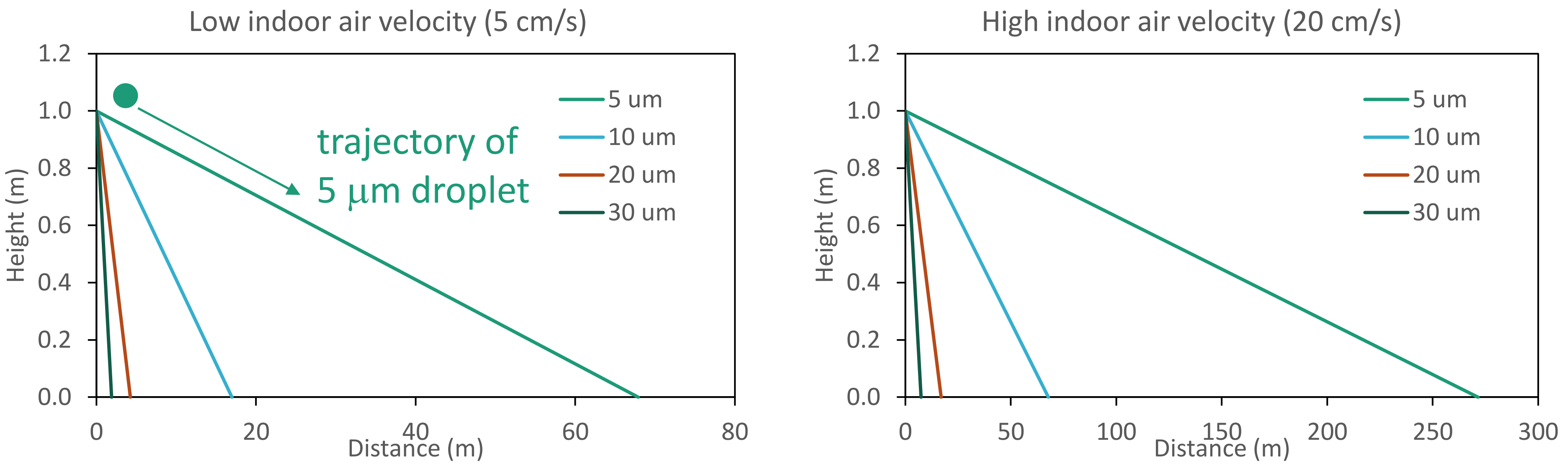
dynamic viscosity of air



Droplets smaller than 10 µm can remain suspended for many minutes

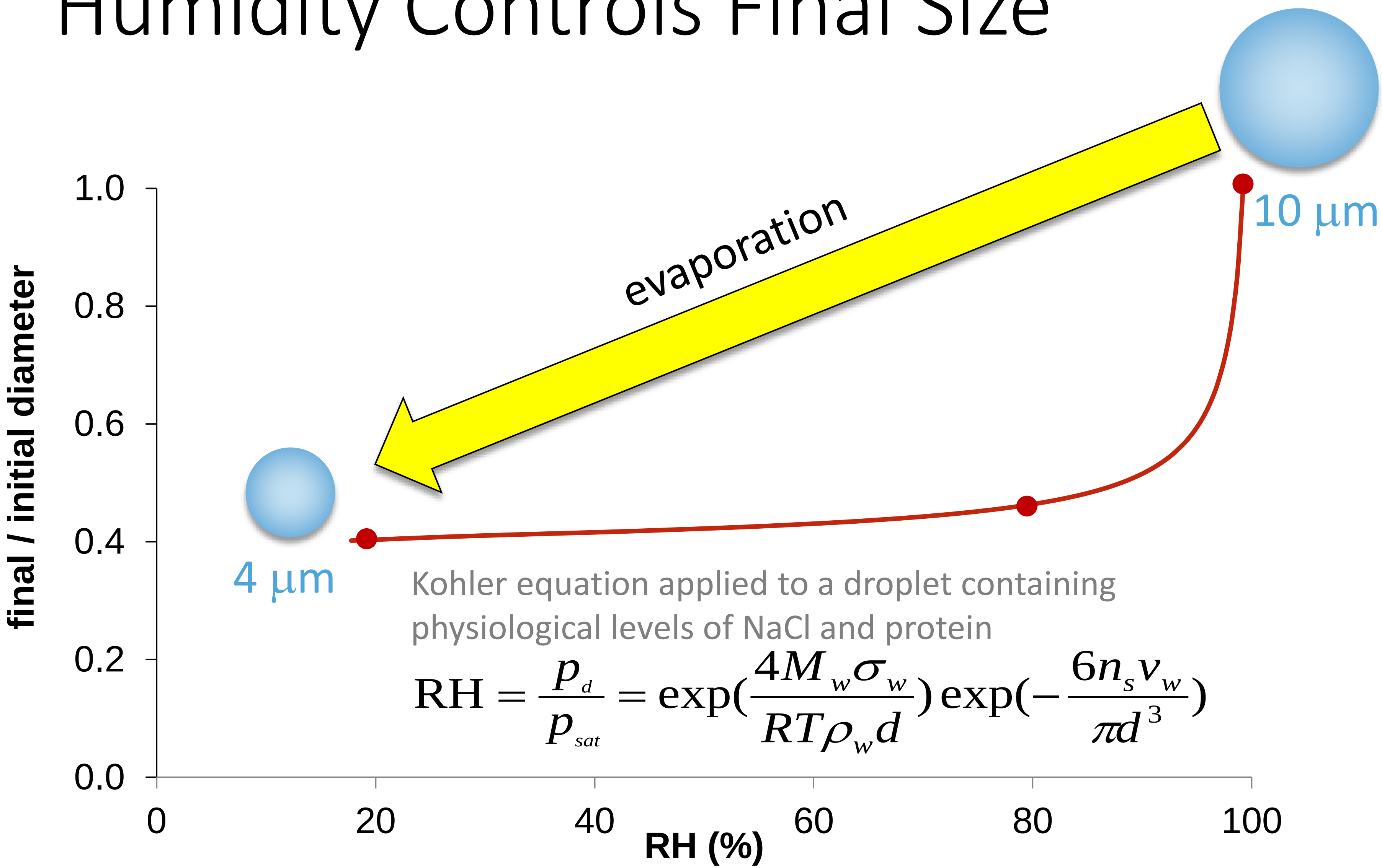
Droplets Can Travel More Than 2 m

Position of droplets released from a height of 1 m



Nazaroff, 2020, personal communication

Humidity Controls Final Size

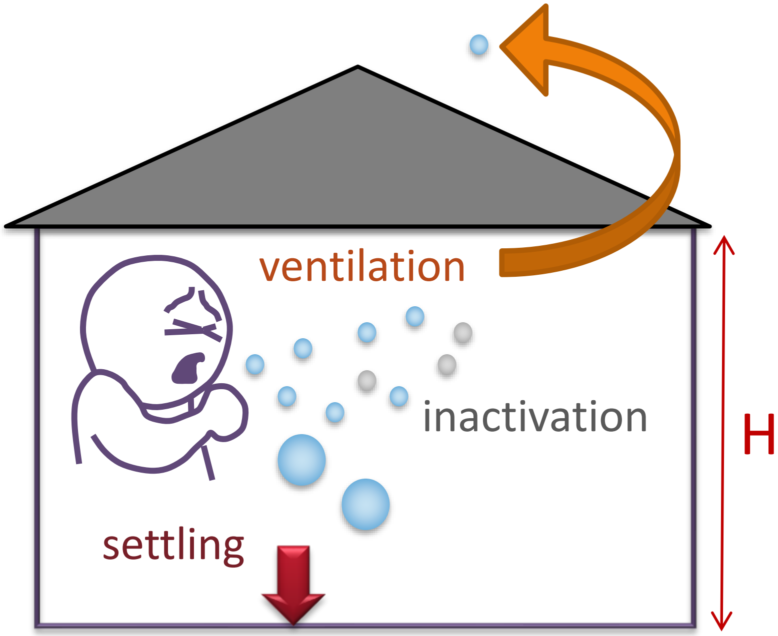


Kohler equation applied to a droplet containing physiological levels of NaCl and protein

$$\mathrm{RH} = \frac{p_d}{p_{sat}} = \exp\left(\frac{4M_w\sigma_w}{RT\rho_w d}\right)\exp\left(-\frac{6n_s v_w}{\pi d^3}\right)$$

Mikhailov, 2004, *Atmos. Chem. Phys.*, https://www.atmos-chem-phys.net/4/323/2004/

Virus Dynamics in Indoor Air



$$\frac{dC_d}{dt} = -\left(\frac{v}{H} + \lambda + k\right)C_d$$

settling — ventilation (air-exchange) — inactivation

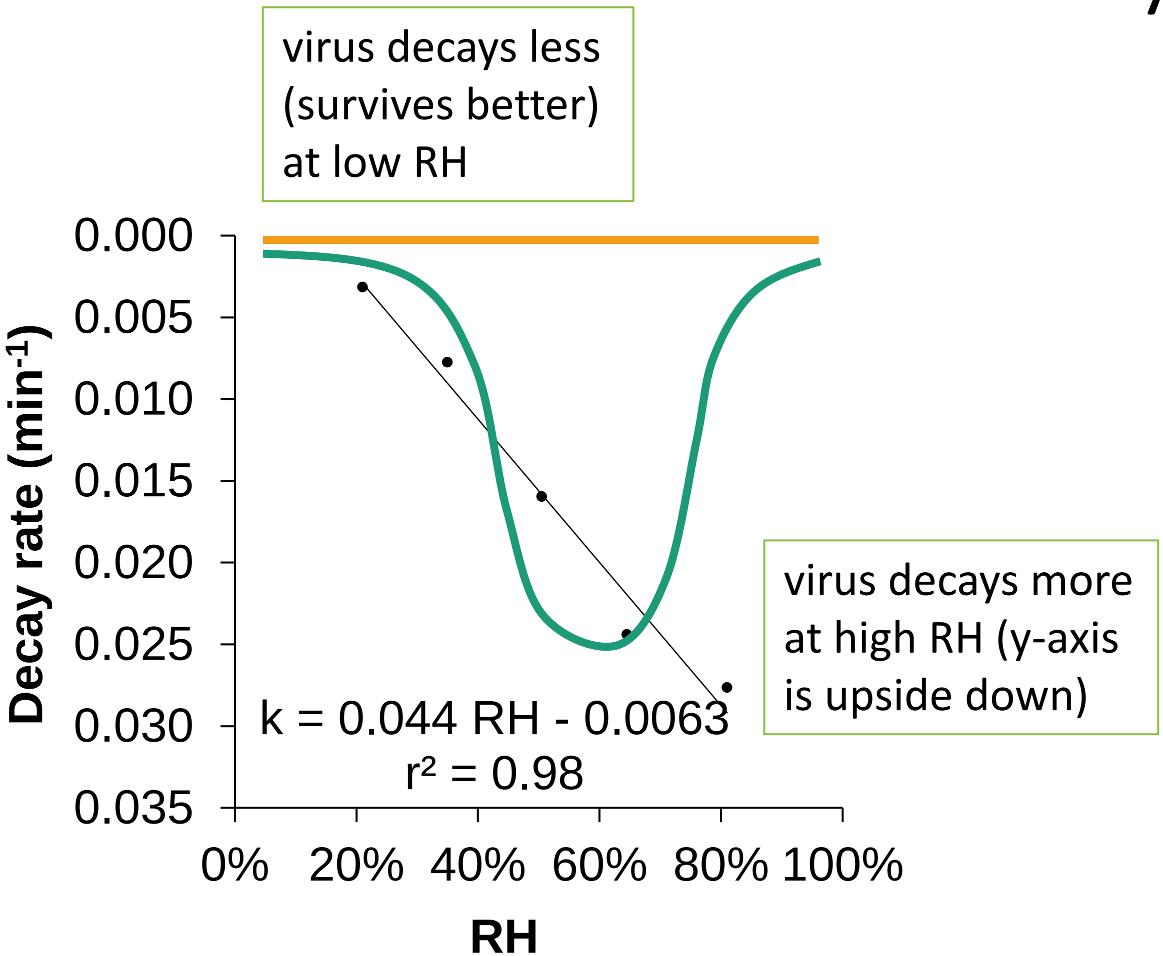
concentration of infectious virus in aerosols of <u>diameter *d*</u>

- Settling velocity *v* depends on diameter *d*
- Diameter depends on RH
- Inactivation rate *k* depends on RH

relative humidity (RH)

Yang and Marr, 2011, *PLoS One*, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3123350/

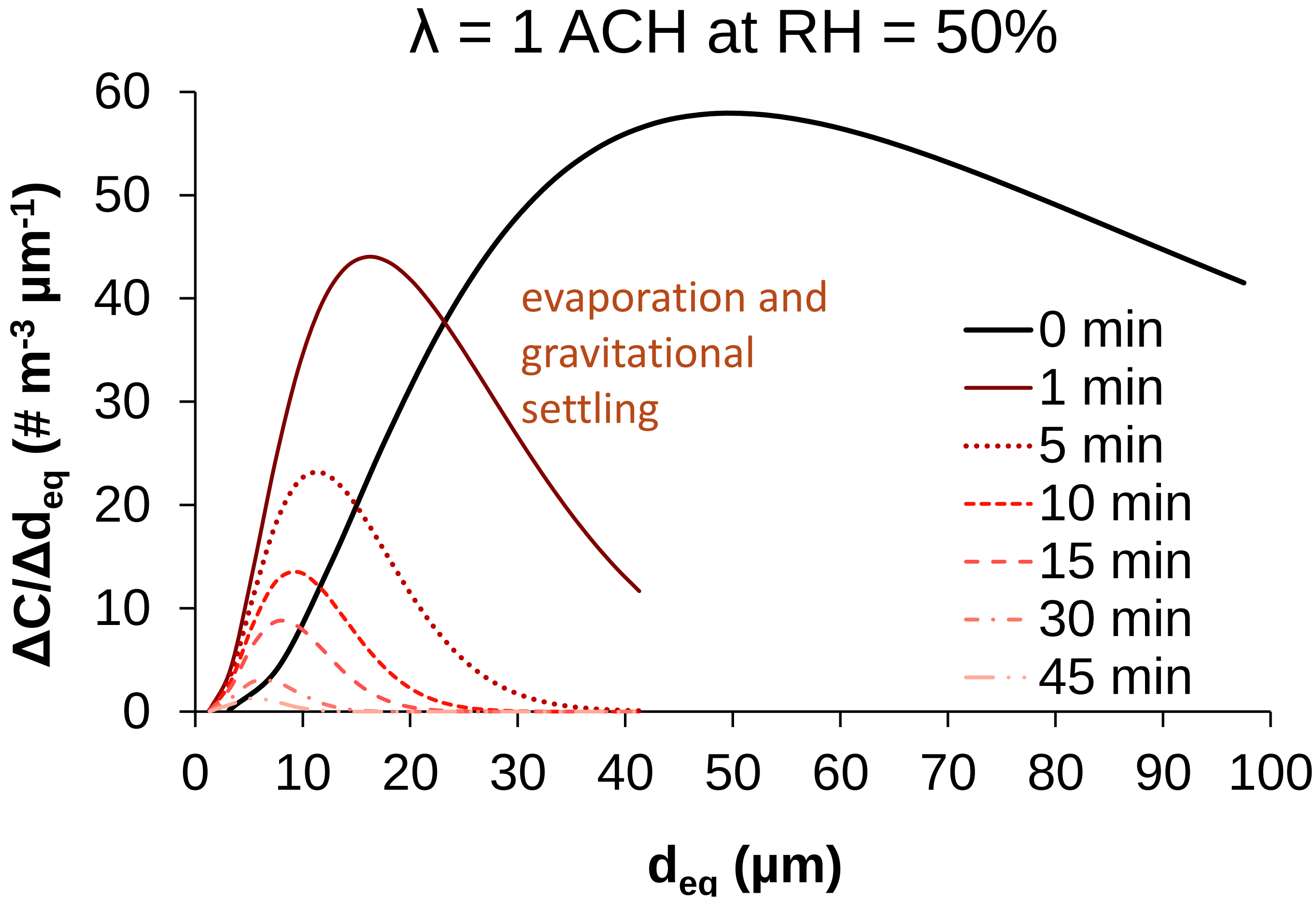
Aerosolized Flu Viability vs. RH



But this relationship is more **U-shaped**, with maximum decay at 40-70% RH, in fluid containing proteins, and there is **no decay** over 1 hr when supplemented with material from human bronchial cells.

Yang and Marr, 2011, *PLoS One*, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3123350/;Kormuth and Lin et al., 2018, *J. Infect. Dis.*, https://academic.oup.com/jid/article/218/5/739/5025997

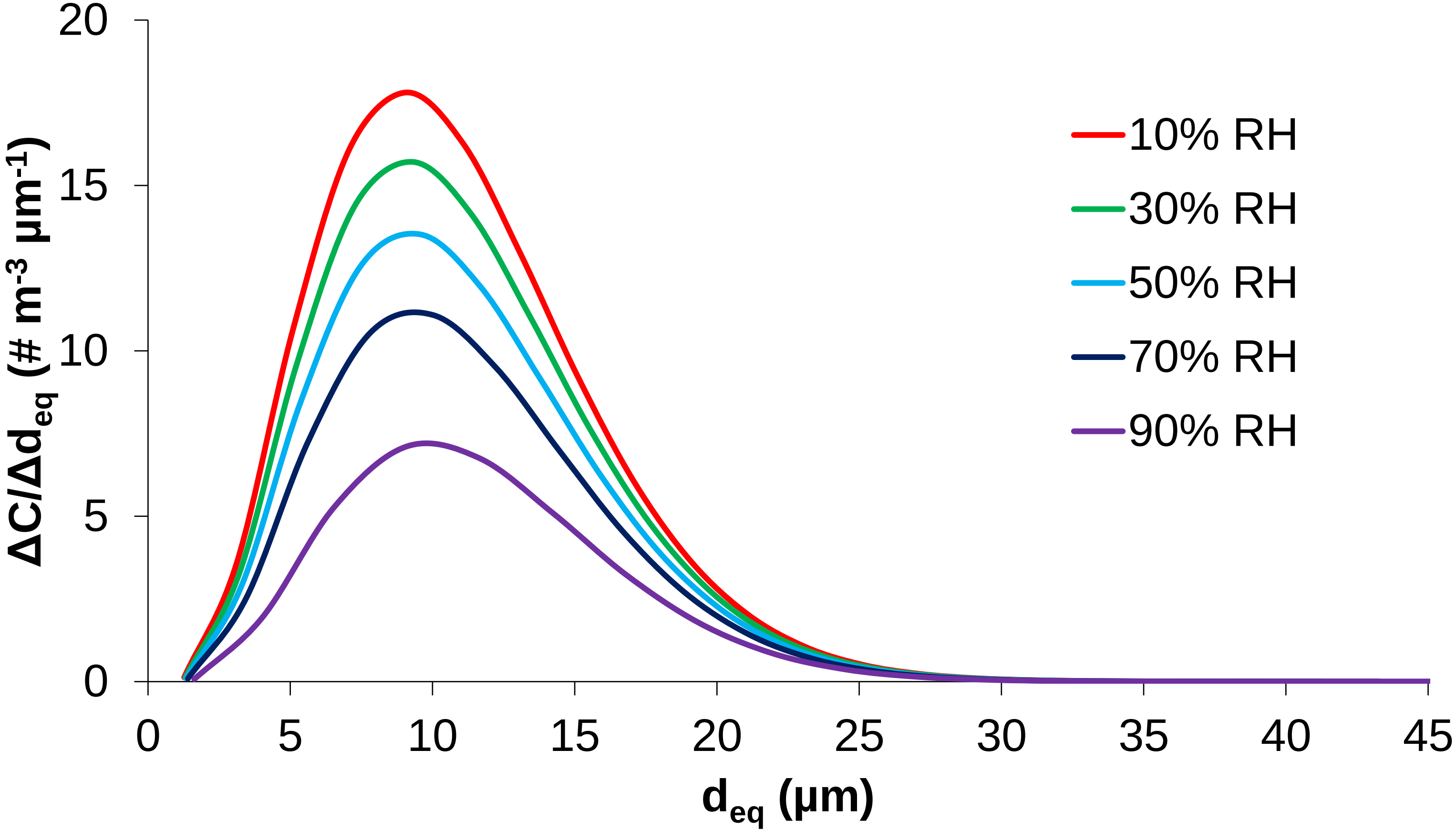
Virus-Aerosols From a Cough



There is a size shift due to loss of larger droplets by gravitational settling.

Yang and Marr, 2011, *PLoS One*, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3123350/

Infectious Concentrations vs. RH

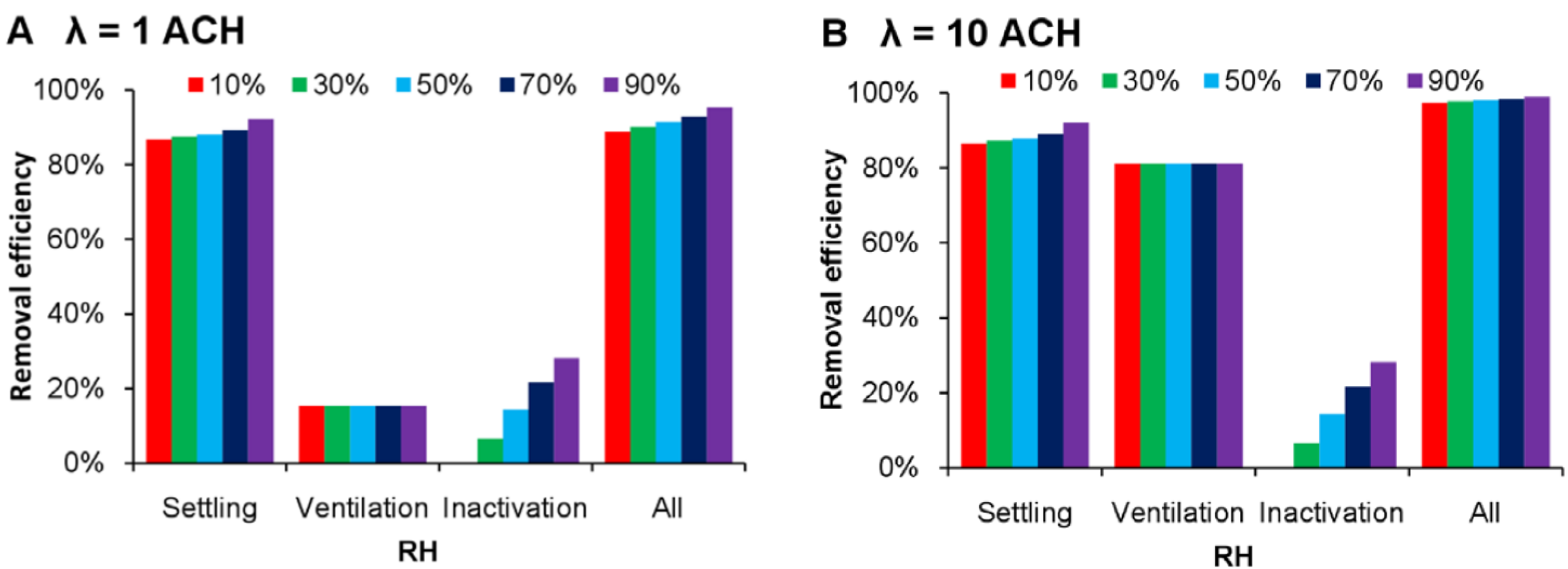


Concentrations are higher at lower RH mainly because lab-determined inactivation rate is lower.

Yang and Marr, 2011, *PLoS One*, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3123350/

Removal Mechanisms

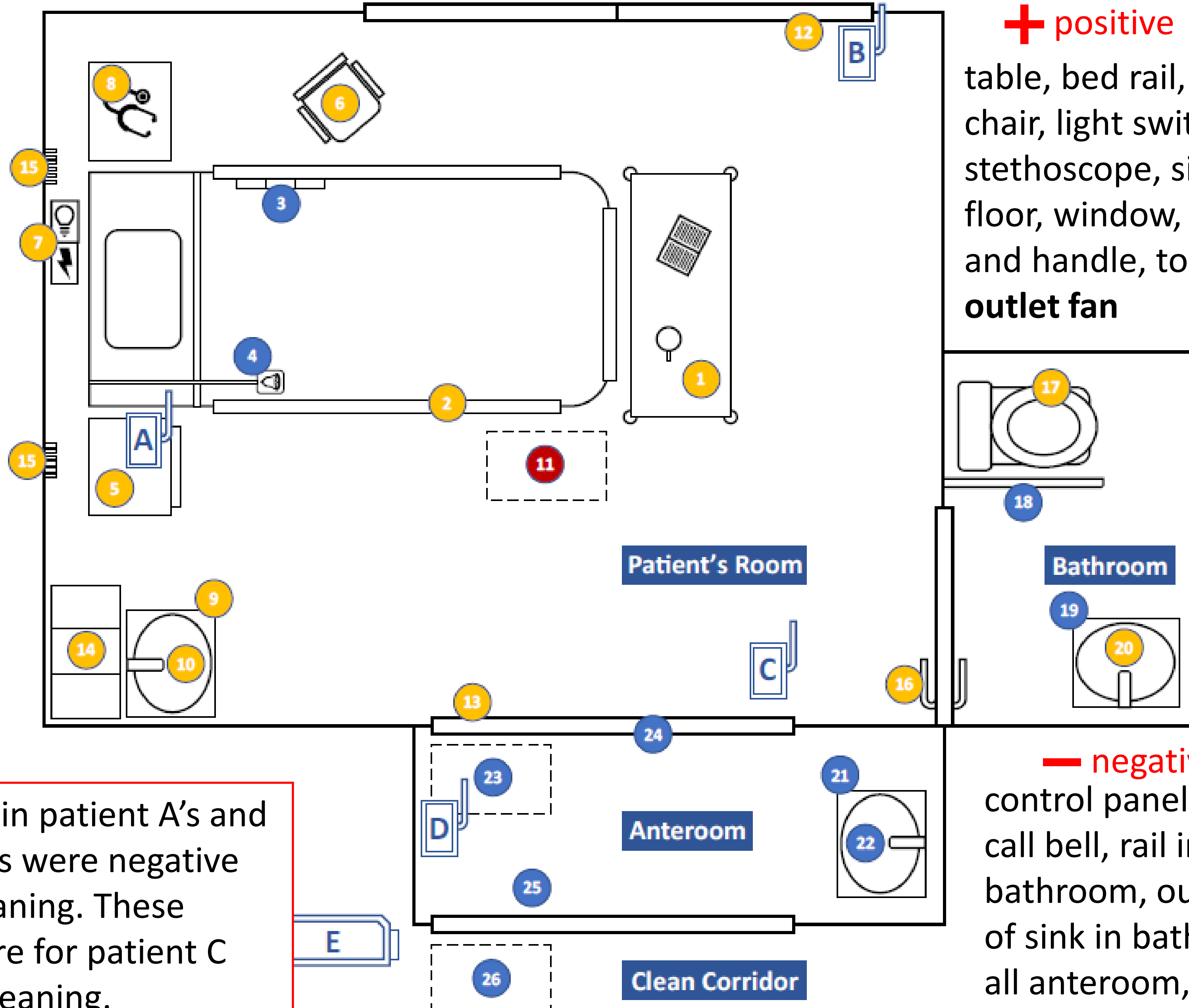
- Settling: main removal mechanism, efficient for large but not small droplets
- Ventilation: effective for all sizes, important in public places
- Inactivation: effective for all sizes, important for small droplets



Yang and Marr, 2011, *PLoS One*, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3123350/

Viruses can be removed from indoor air by settling, ventilation, and inactivation; some of these processes depend on humidity.

What do we know about SARS-CoV-2 in droplets/aerosols?



+ positive

table, bed rail, locker, chair, light switches, stethoscope, sink, floor, window, door and handle, toilet, **air outlet fan**

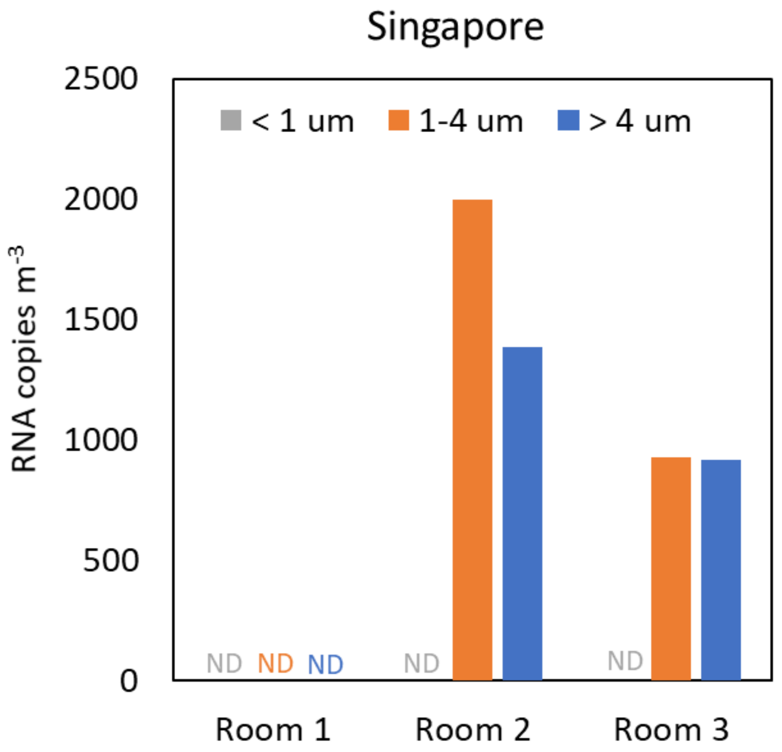
– negative

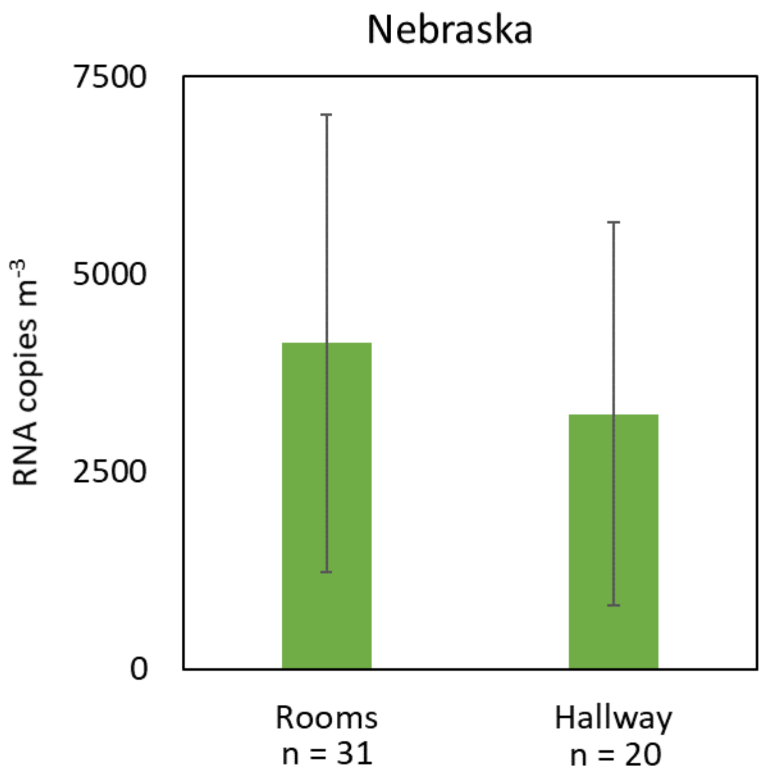
control panel on bed, call bell, rail in bathroom, outer rim of sink in bathroom, all anteroom, **air**

Samples in patient A's and B's rooms were negative after cleaning. These results are for patient C before cleaning.

Ong et al., 2020, *JAMA*, https://jamanetwork.com/journals/jama/fullarticle/2762692

Airborne Viral RNA in Hospitals

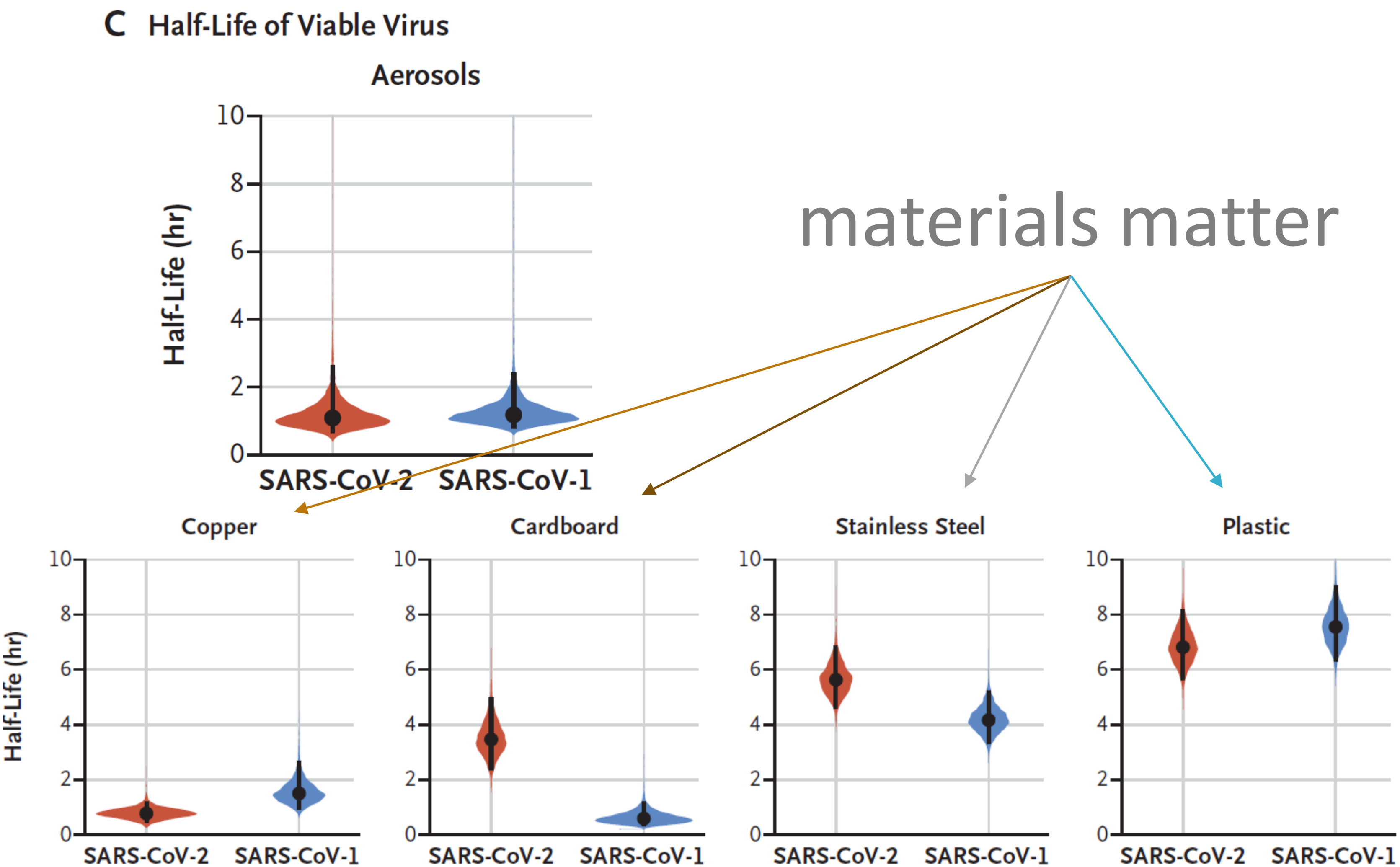




I estimate a viral RNA emission rate of 10,000 genome copies per minute in "small" droplets.

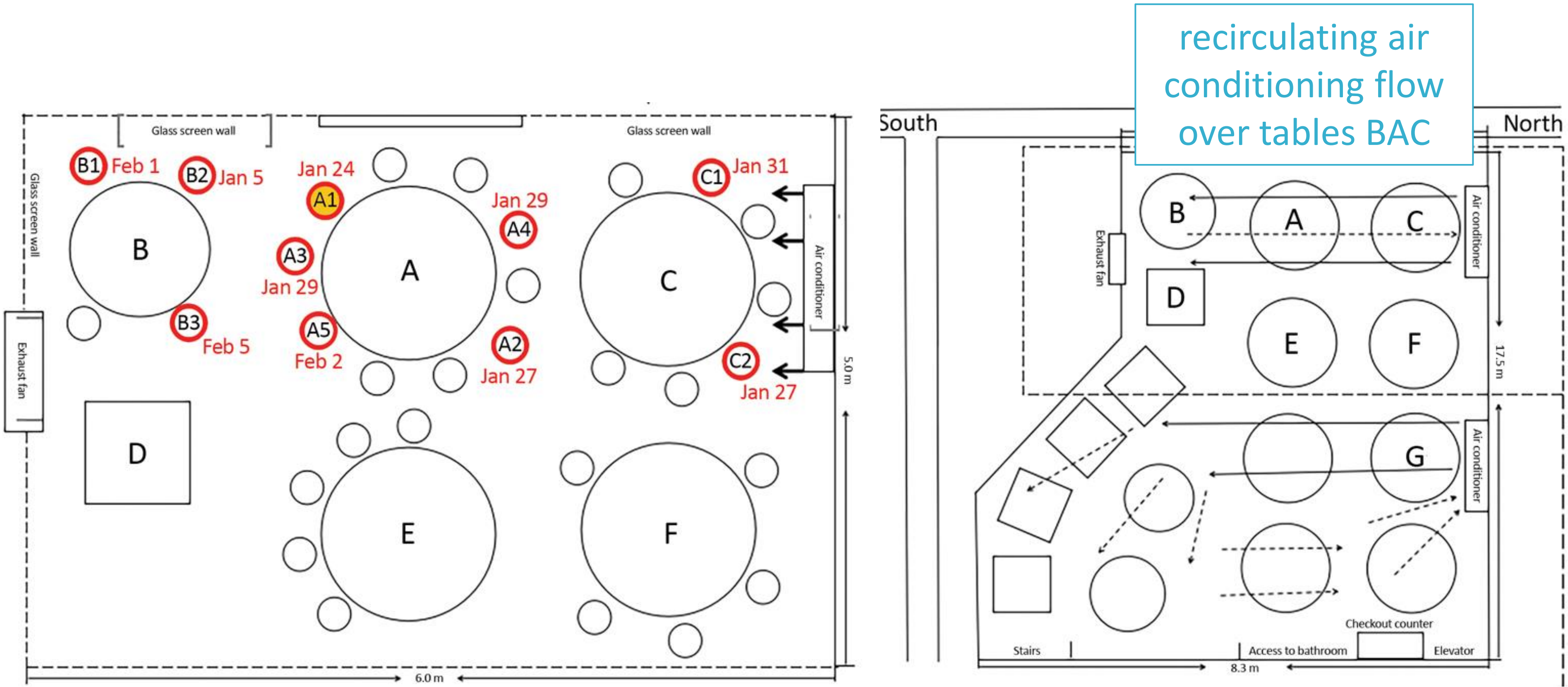
Chia et al., 2020, https://www.medrxiv.org/content/10.1101/2020.03.29.20046557v2; Santarpia et al., 2020, https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v2

SARS-CoV-2 Survival



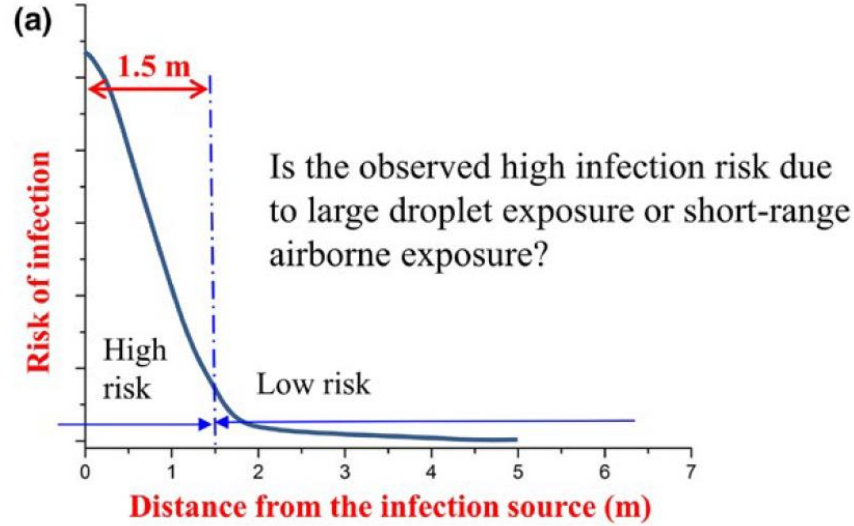
van Doremalen et al., 2020, *NEJM*, https://www.nejm.org/doi/full/10.1056/NEJMc2004973

Restaurant Outbreak



Liu et al., 2020, *EID*, https://wwwnc.cdc.gov/eid/article/26/7/20-0764_article

Major Unknowns



- Which transmission route is dominant: direct contact, indirect contact with contaminated objects (fomites), inhalation of aerosols, deposition of droplets?
- How much virus is released in what size aerosols at different stages of infection?
- How well does SARS-CoV-2 survive in aerosols under real-world conditions?
- How does humidity affect transmission?

Liu et al., 2016, *Indoor Air*, https://onlinelibrary.wiley.com/doi/abs/10.1111/ina.12314

Opportunities for Civil Engineers

- Design buildings and transportation systems whose ventilation systems minimize the risk of airborne transmission.
- Integrate treatment technologies, such as germicidal UV and HEPA filtration, in confined spaces.
- Select materials that are less favorable for pathogen survival in high-touch areas.
- Apply environmental engineering fundamentals to understand fate and transport of pathogens in the built environment.

Acknowledgments

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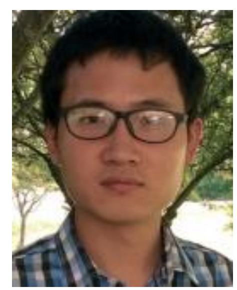
Peter Vikesland
Haoran Wei
Wan Yang





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NNCI nano

Questions?

Linsey Marr, Ph.D.: lmarr@vt.edu

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ESSENTIAL BUILDINGS: US ARMY CORPS OF ENGINEERS ASSISTANCE WITH INCREASING HOSPITAL CAPACITY

Date:

Thursday, April 23, 2020 | 2:00 – 3:00 p.m. [Eastern]

Did you know that civil engineering issues and concepts are on the front lines of the current coronavirus/COVID-19 pandemic? Join these civil engineering experts as they explore the intersection of civil engineering and the pandemic that is challenging health systems and upending daily lives around the globe.

The focus of this webinar: One of the biggest challenges facing the country in the COVID-19 crisis is the anticipated shortage of hospital facilities to treat the critically ill. Enter the US Army Corps of Engineers who is assisting with increasing capacity in existing facilities and converting other buildings into temporary hospitals. Learn from a member of the Construction Branch about the Corps' mission, and how it took on this mission.

Presenter: **Kenny Simmons, AIA, LEED AP BD+C**, is an Architect in the Construction Branch at the U.S. Army Corps of Engineers, headquarters in Washington, DC.

Thank you for participating!

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