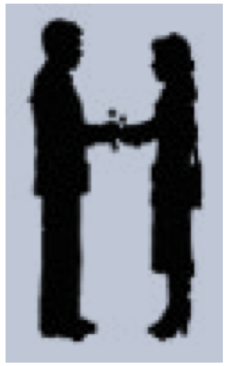
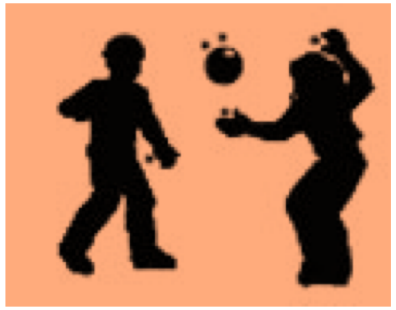
Where is SARS-CoV-2 and how does it get there?
Current and future research on environmental surveillance and transmission

Part 2. SARS-CoV-2 in aerosols



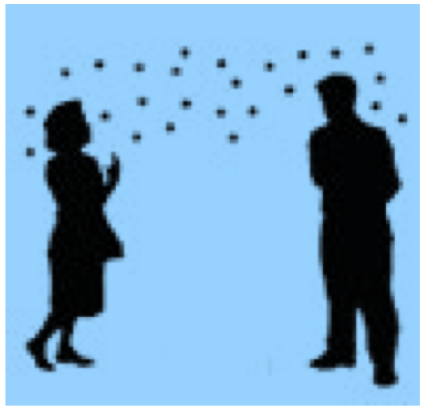
direct contact



indirect contact

close-range only (<2 m)

large droplets



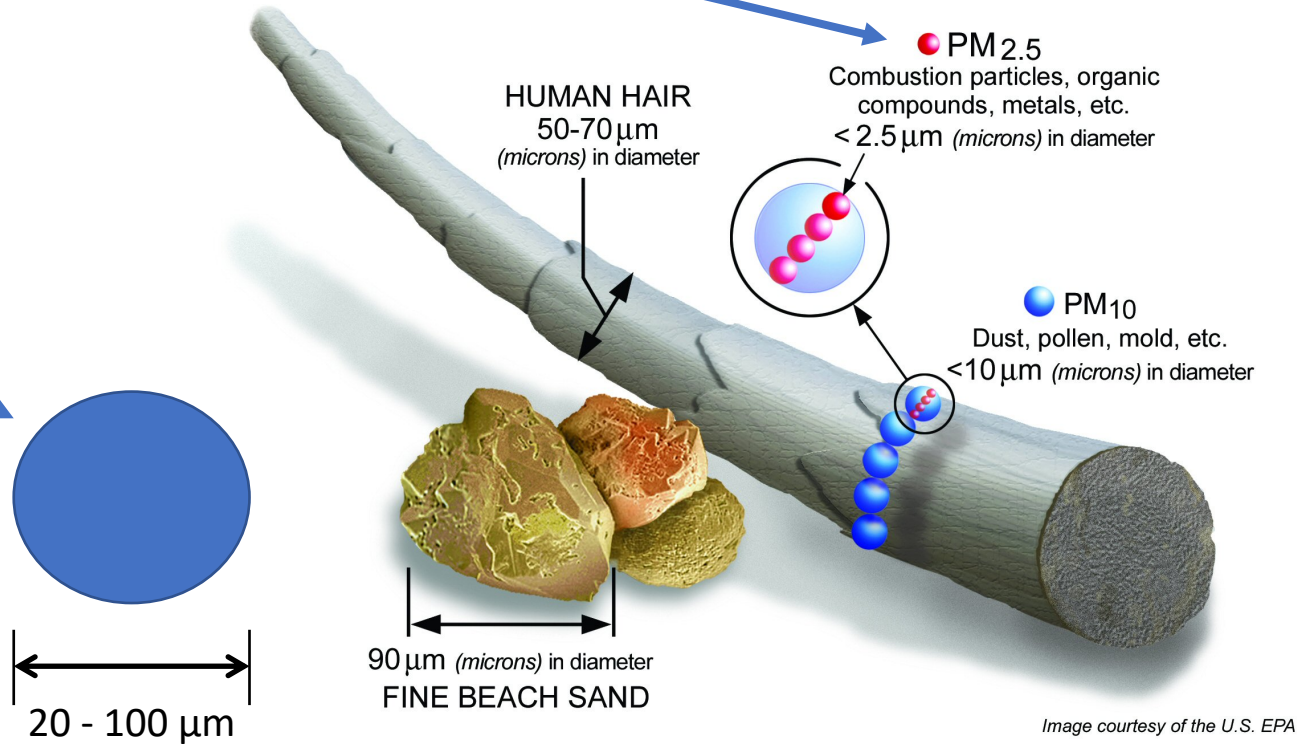
aerosols

aerosols

Aerosols: liquid or solid particles suspended in air (or other gas)

Droplets:

So large,
Hard to
remain
airborne
(liquid)

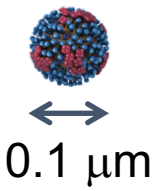


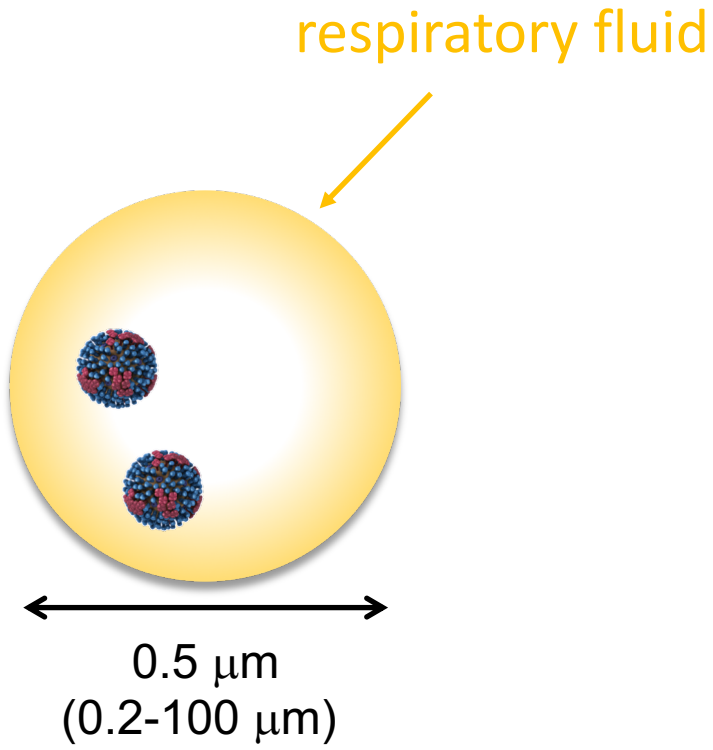
20 - 100 µm
Like cloud or rain droplets

https://www.cdc.gov/flu/resource-center/freeresources/graphics/images.htm, http://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

Aerosol generated by Breathing, speaking, and coughing

High air velocity shears respiratory fluids during expiration

Modes:

< 0.3 (possible)

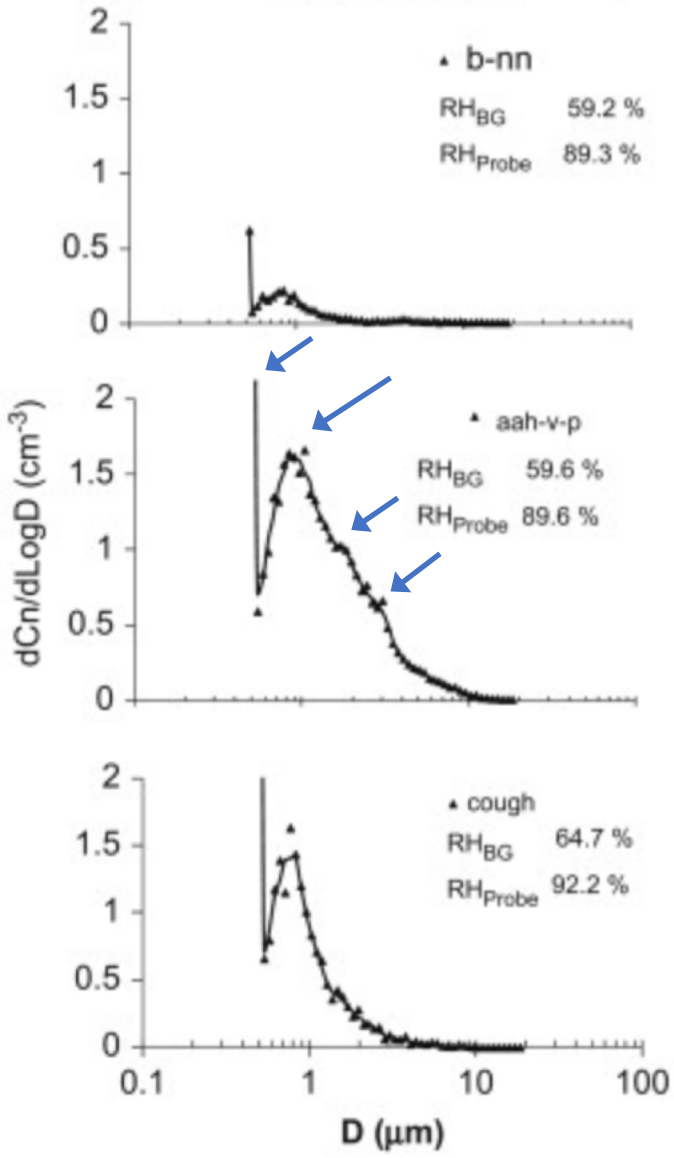
0.8 µm (largest mode)

2-4 µm (two modes)

100 µm (smaller)

Droplets (100 µm):
By number, 0.8µm mode is 100 times larger (coughing)

Aerosol size distribution (by number)



Breathing

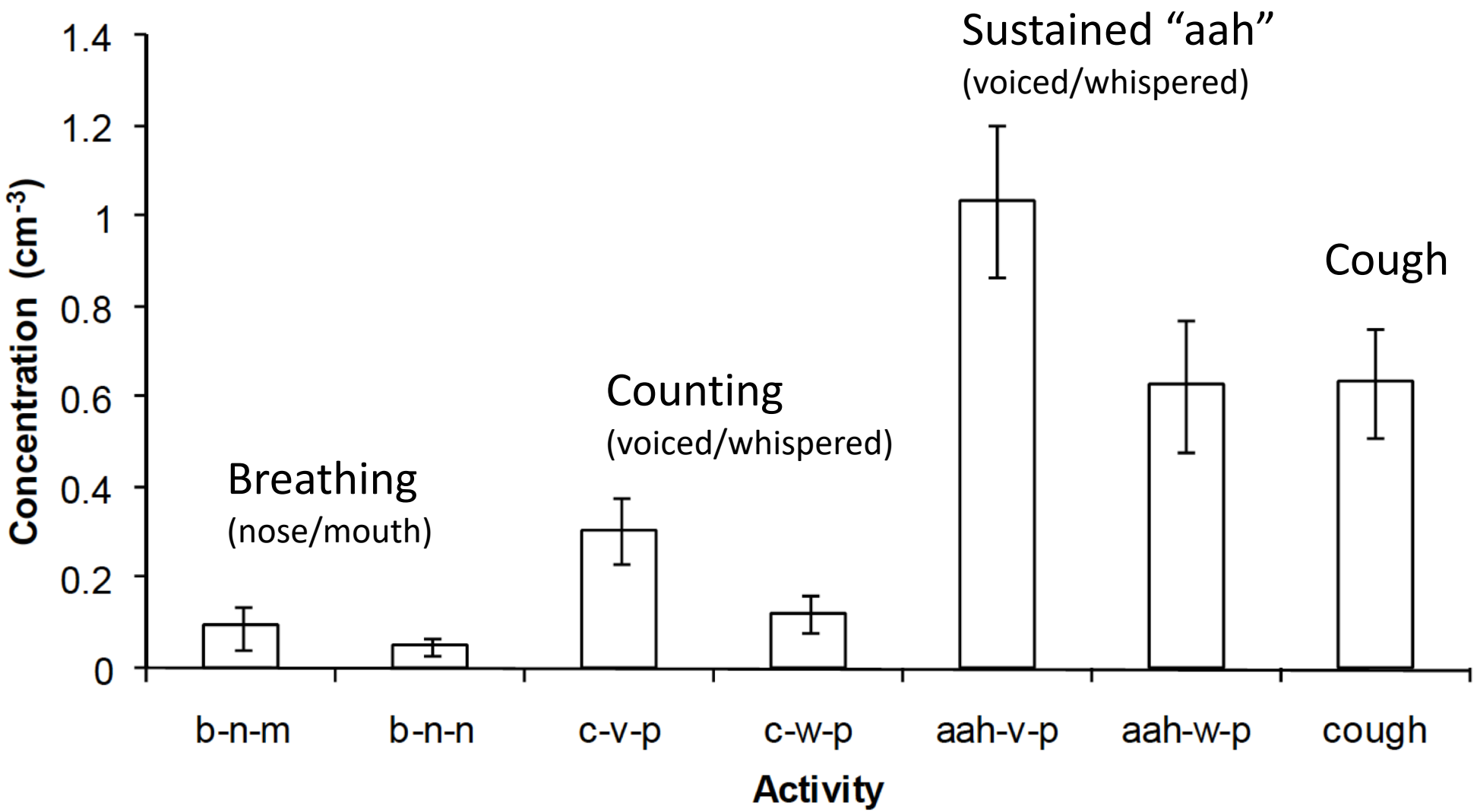
Speaking/singing

Also droplets near 100 µm

Coughing

Morowska et al.
Journal of Aerosol Science
Volume 40, Issue 3, March 2009, Pages 256-269

Relative emission rate of aerosol particles between activities



Morowska et al. **Journal of Aerosol Science** Volume 40, Issue 3, March 2009, Pages 256-269

Infected people *could* emit viable CoV-2-containing aerosol all the time

CoV-2 is present in the respiratory tract (Zhu et al., 2020)

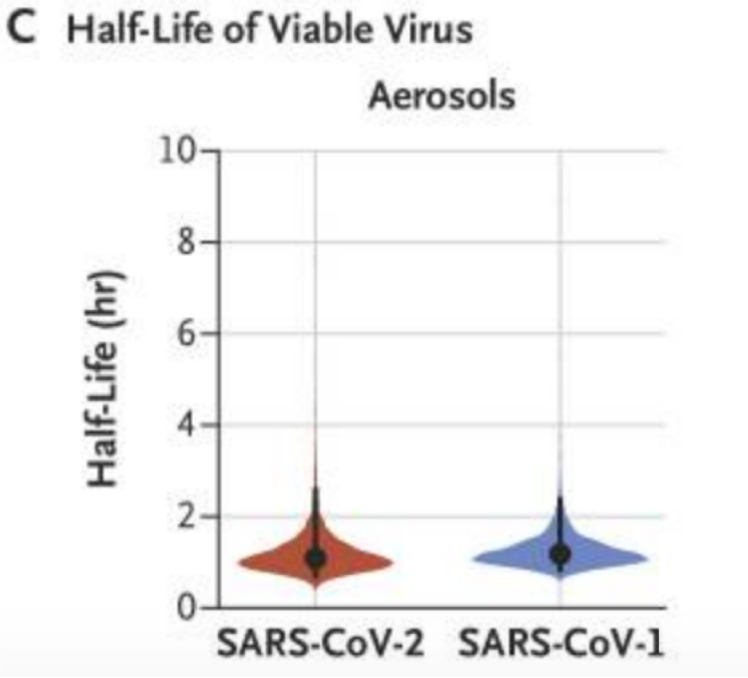
Booth et al (2005) established that hospitalized SARS patients emit viable aerosolized virus

CoV-2 has been measured in hospital aerosol:

- infectious, replicating virions measured in three <1 μm aerosol samples in hospital rooms (Santarpia et al., *unrefereed preprint* 2020)
- And in 4 samples from a pair of patients (Lednicky et al.,)

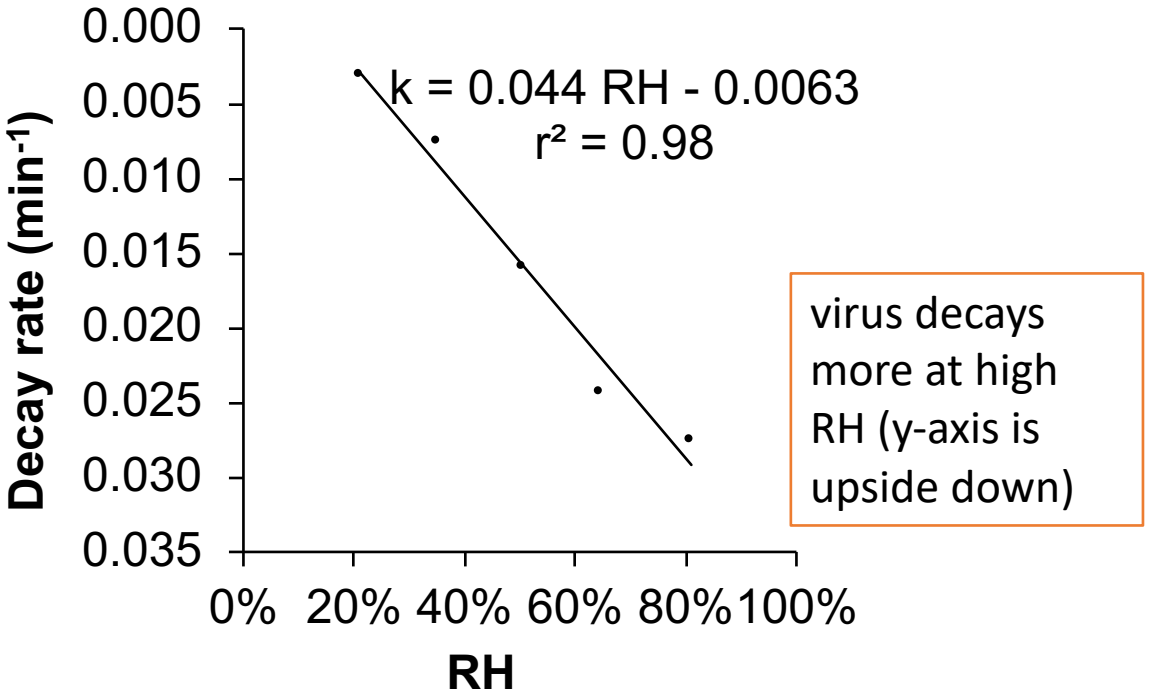
Zhu, et al. (2020) *N. Engl. J. Med.,* 382, 727-733
Booth et al. (2005) *J. Infect. Diseases*., 191,1472-1477
Liu et al. (2020) *bioRxiv unrefereed preprint*. doi: 10.1101/2020.03.08.982637
Asadi et al. (2020) *Aerosol Sci. Technol.,* 54, 635-638
Santarpia et al (2020) medRxiv unrefereed preprint. doi.org/10.1101/2020.07.13.20041632
Lednicky et al (2020) medRxiv unrefereed preprint. doi.org/10.1101/2020.08.03.20167395

Viability of aerosolized CoV-2. papers report half-life of 1 to several hours. (for particles < 5 µm)



van Doremalen, N. et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-209 CoV-1. New England Journal of Medicine, 2020; 382: 1564-1567.

Viruses remain viable longer at lower RH (influenza); lower temps



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

Collection of *viable* virus aerosol (MS2)

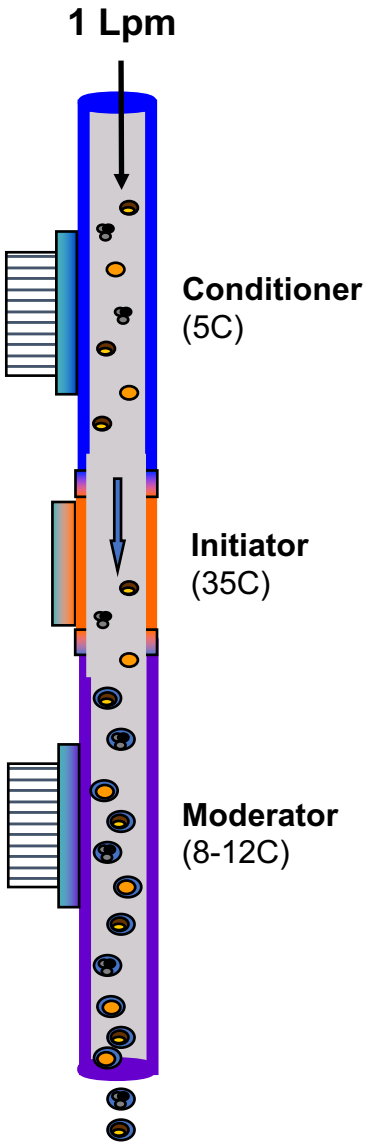
BioSpot's virus collection efficiency is 10-100 fold that of SKC BioSampler

Concentrated	Increased analysis sensitivity (LOD/LOQ)
High Efficiency	>95% for particles 5nm – 10µm diameter
Sample Quality	Maintain sample integrity and microorganism viability

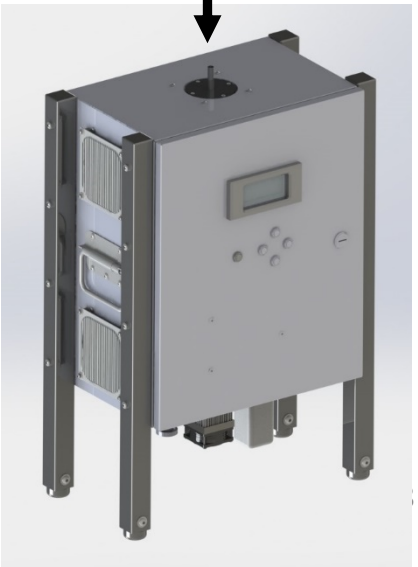
Aerosol scientists: Turpin, Surratt, Baumann
Indoor air: Morrison, Turpin
Microbiologists: Brown, Stewart, Fisher
Infectious disease: Baric

Controlled experiments, well-characterized aerosols, varied environmental conditions

M. Pan et al., Journal of Applied Microbiology; 120, 805-815: 2016.



BioSpot operates bundle of eight: Hence, total F is **8 Lpm**



Size determines time airborne

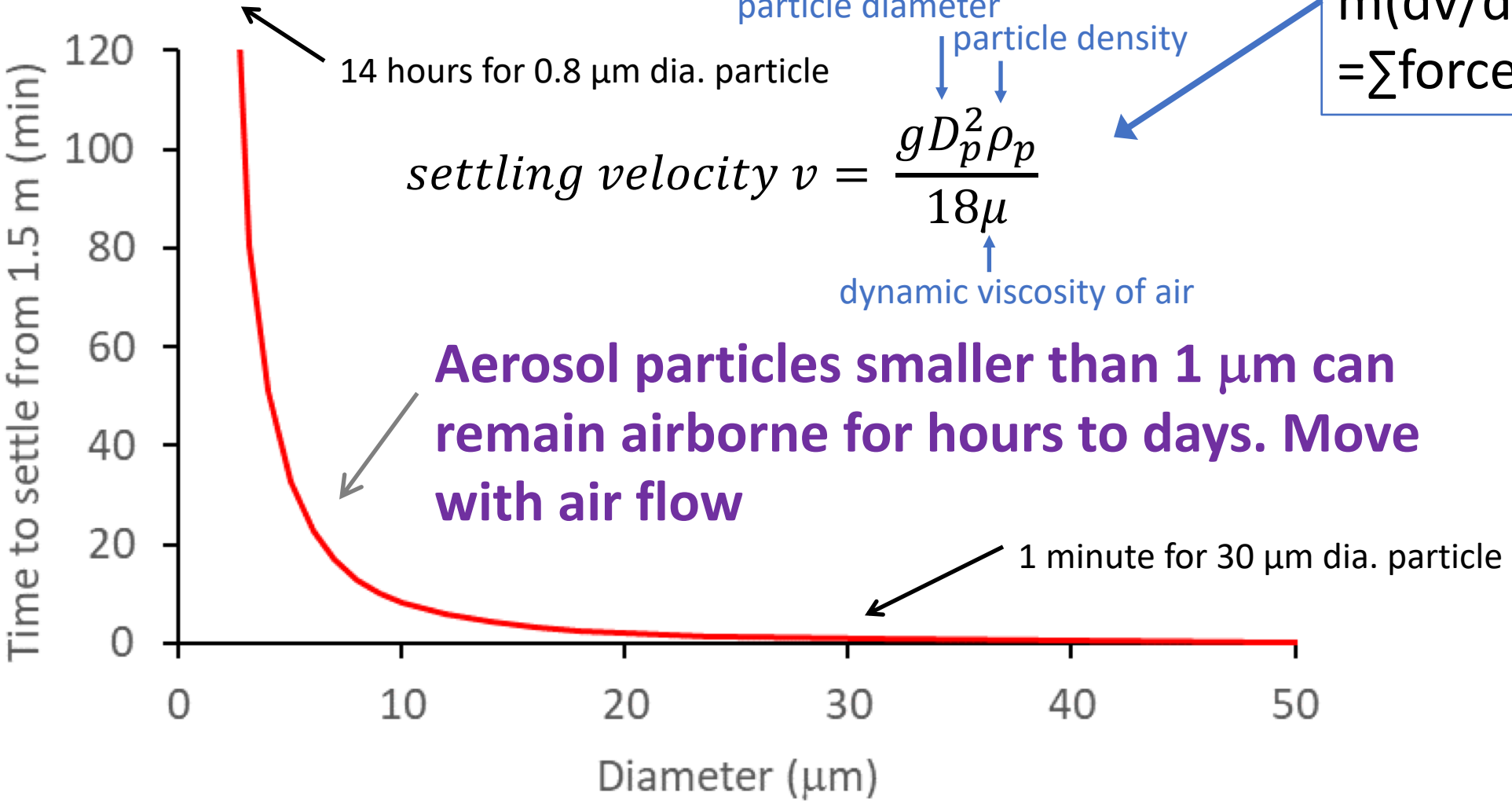
Solve:
m(dv/dt)
=∑forces

particle diameter

particle density

$$settling\ velocity\ v = \frac{g D_p^2 \rho_p}{18\mu}$$

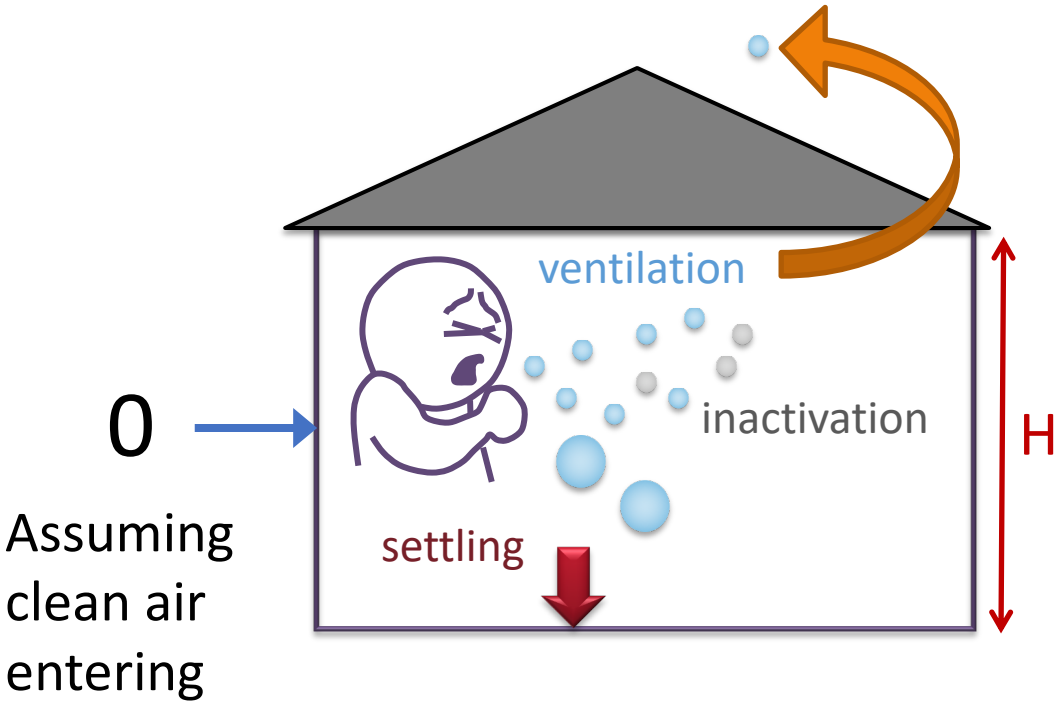
dynamic viscosity of air



Aerosol particles smaller than 1 µm can remain airborne for hours to days. Move with air flow

Virus Dynamics in Indoor Air

estimate concentration of virus-containing particles (number conc.)



deposition air-exchange rate Inactivation

$$VdC/dt = S - (k_{dep} + \lambda + k_{inact.})CV$$

$$C_{SS} = \frac{S}{V(k_{dep} + \lambda + k_{inact})}$$

S = Aerosol-borne virus emission rate

$$\lambda = \frac{\text{Volumetric flow rate } (ft^3/hr)}{\text{Room volume } (ft^3)}$$

new home: 0.5 hr^{-1}; Classrooms: 1 - 5 hr^{-1}; Grocery: 5 hr^{-1}; Hospital: 15 hr^{-1}

At steady state:

$$C = \frac{S}{V(k_{dep} + \lambda + k_{inact})}$$

$$\text{Dose} = C \times \text{InhR} \times \text{ET}$$

Nice assessment tool linked here

Time to reduce conc by 90%:

$$t = \frac{-\ln(0.1)}{(k_{dep} + \lambda + k_{inact})}$$

$t = 1.5$ hr for $\lambda = 0.5\ \text{hr}^{-1}$

$t = 9$ min for $\lambda = 15\ \text{hr}^{-1}$

We know:

- <6 feet – higher droplet and aerosol conc.
- > 6 ft - longer you stay, higher your dose

We do not really know:

- The emission rate of viable virus
- The dose – response

(how high a dose would it take to be infected from across the room?)

Skagit Valley Chorale

Precautions to avoid contact
Transmission broadly spread across room
52 + index case of 61 total people

Authors estimate, from this and other ***singing*** events: S = 1,000 – 10,000 quanta/hr

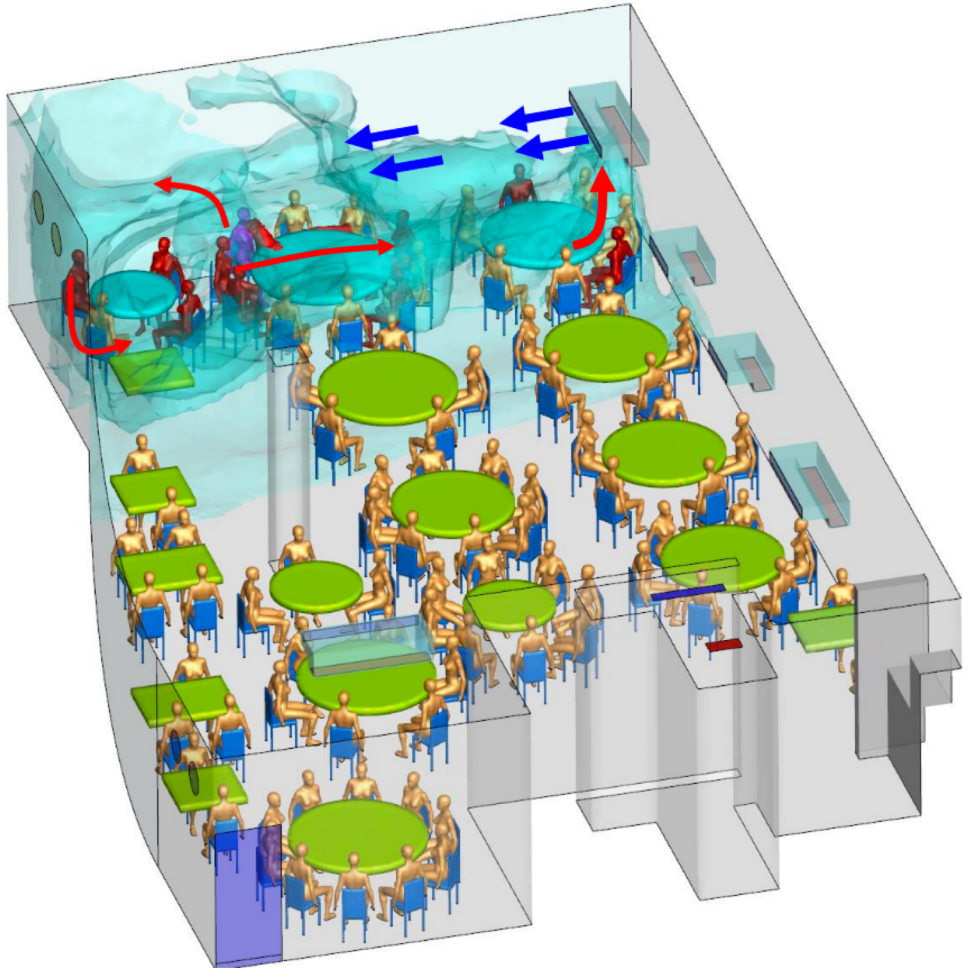
(Buonano – predicts **1000 quanta/hr** for speaking with "light activity, **300 quanta/hr** for speaking at rest – greater than influenza and less than measles)

*a "quantum" is the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons

Miller et al. (2020) medRxiv, doi: https://www.medrxiv.org/content/10.1101/2020.06.15.20132027v2.full.pdf+html

Dinner in China

Waiters not infected; families came different times



Li et al. (2020) medRxiv, doi: https://www.medrxiv.org/content/10.1101/2020.04.16.20067728v1

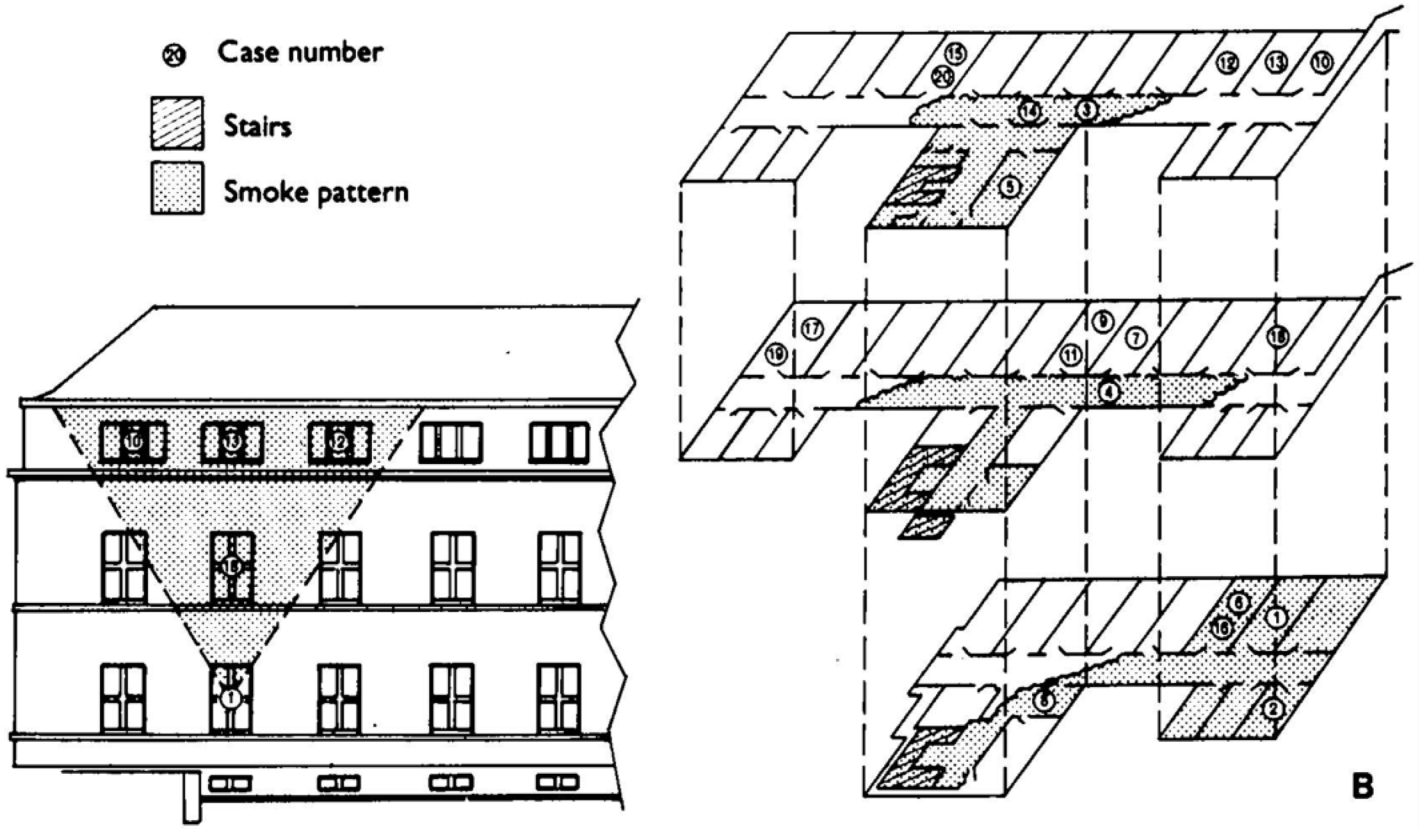
Quanta emission rates for **influenza** have been reported to be in the range 15 - 128 quanta h^{-1}

for **measles**: 5,580 q h^{-1}

and for **tuberculosis**: 1.25 to 30,840 q h^{-1}
(the high value attributed to intubation)

OF COURSE: no way to know for certain that there was not other contact

It does not look like CoV-2 is spread through the air as easily as smallpox or measles



Airborne Spread of Smallpox in the Meschede Hospital

Transmission of smallpox via airborne spread documented

- Patient on ground floor of hospital with natural ventilation
- Spread for case patient to other patients on floor and higher level floors

Fenner. 1988.Fig. 4.9

Skagit Valley Chorale

810 m^3 is 28,600 ft^3
(ROS 133 is 24,200 ft^3)

Inferred S = 970 quanta/hr
Higher than influenza,
lower than measles

Increasing loss rate:
e.g., Ventilation or
HEPA filter air cleaner

Masks – reduce emission
rate

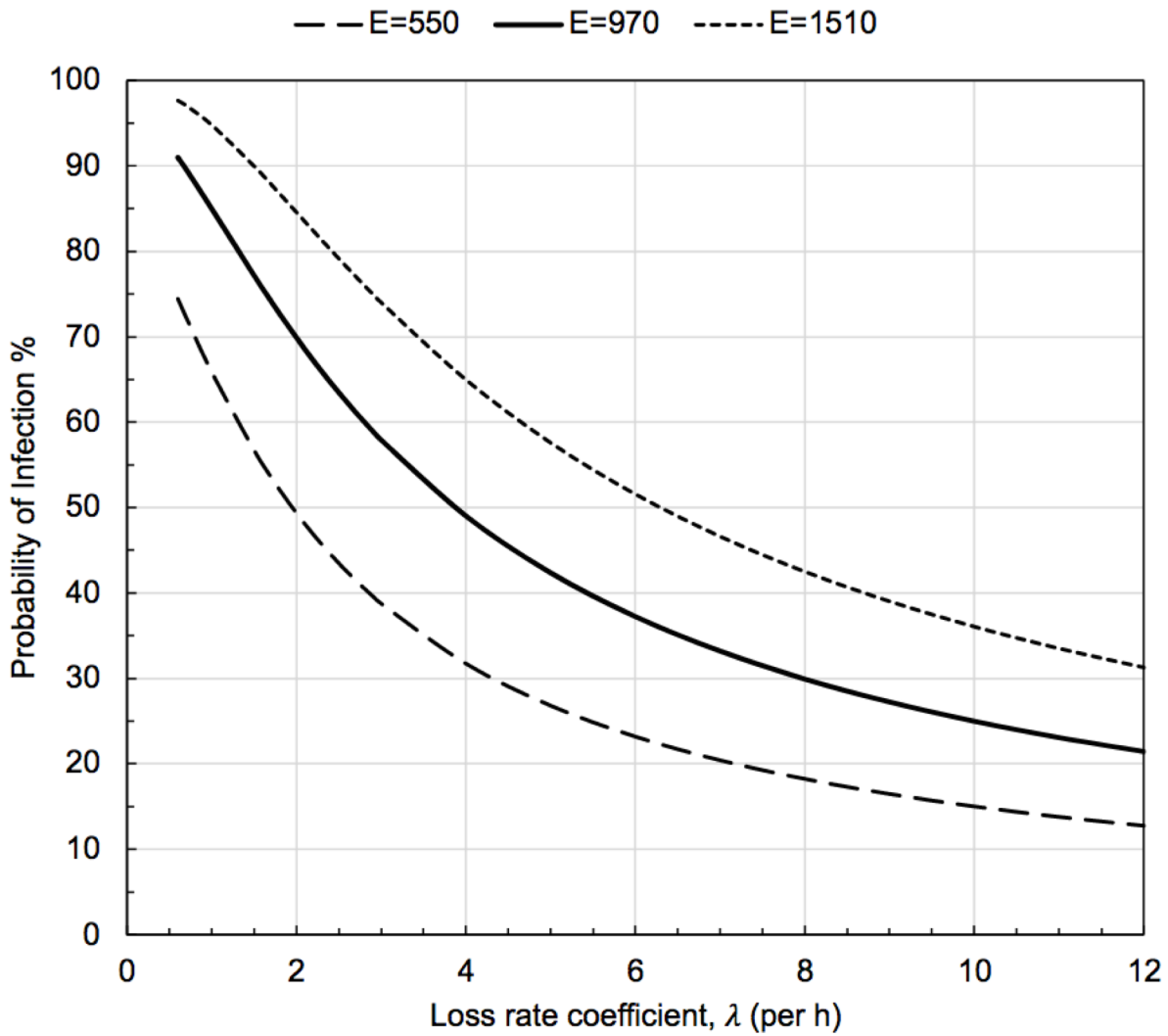


Figure 1. *Probability of infection for each rehearsal participant as a function of loss rates for varying airborne quanta emission rates (E, q h^{-1}). Infection probability is plotted for the predicted mean emission rate (970 q h^{-1}) and the 10th and 90th percentile emission rates (550 and 1510 q h^{-1}, respectively.) A rehearsal duration of 2.5 hours, an indoor volume of 810 m^3 and a volumetric breathing rate of 1.0 m^3 h^{-1} were assumed.*

Skagit Valley Chorale

Effect of reduced exposure time
2.5 hr to 30 min

MASKS/testing: reducing *S* by a factor of 10 reduces probability by factor of 10

Source reduction is most effective approach

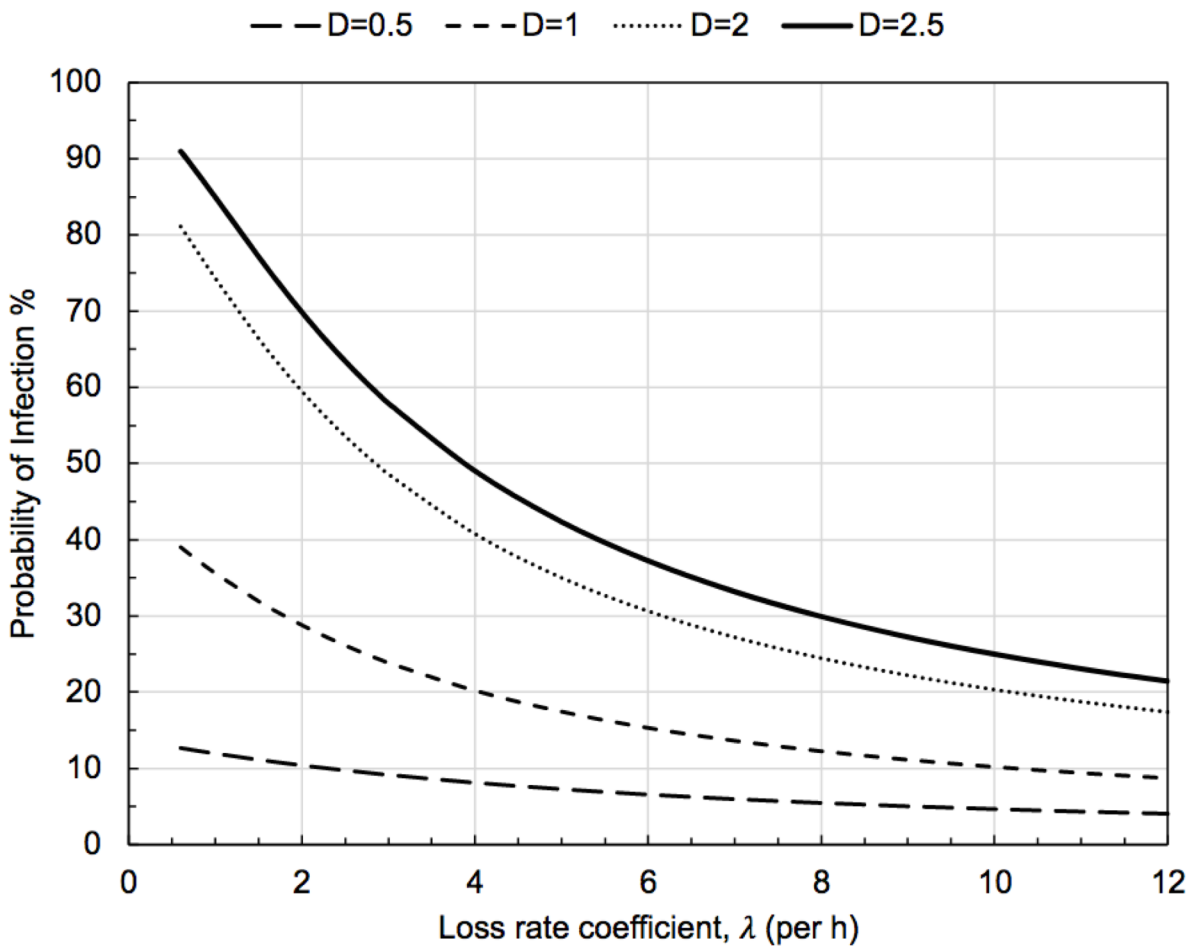


Figure 2. *Probability of infection as a function of loss rates for varying event duration (D, h). A mean emission rate (970 q h^{-1}) and constant volumetric breathing rates of 1.0 m^3 h^{-1} were assumed.*

Important lessons

- **Wear a mask (even when more than 6 feet apart)** - test/trace/isolate
- Maintain distance – fewer people (reduces potential total source)
- Do not linger
- Outdoors is safer than indoors

<u>If aerosol transmission is important:</u>

- CDC "exposed" definition (>15 min within 6 feet) is not adequate – could receive the same dose with long (e.g. 8 hour exposure) at > 6 feet

- Will COVID patients infect family members when recovering at home?
- Plexiglass shields only protect against droplets, not aerosols

Save singing for the shower :)

Comments (1)

Mechanistic Transmission Modeling of COVID-19 on the Diamond Princess Cruise Ship Demonstrates the Importance of Aerosol Transmission

Parham Azimi, Zahra Keshavarz, Jose Guillermo Cedeno Laurent, Brent R. Stephens, Joseph G. Allen

doi: https://doi.org/10.1101/2020.07.13.20153049

This article is a preprint and has not been peer-reviewed [what does this mean?]. It reports new medical research that has yet to be evaluated and so should *not* be used to guide clinical practice.

a combination of epidemic, mechanistic transmission, and dose-response modeling with available empirical data on mechanisms of SARS-CoV-2 dynamics and human behaviors

<u>Mean estimates:</u>
short-range 35% long-range 35% fomite transmission 30%

<u>After quarantine began:</u>
Short-range transmission dominated -- due primarily to aerosols, not droplets.

One more message:

CO_2 concentrations are often used as a surrogate measure of the adequacy of ventilation. They can be measured easily, increase with occupancy.

The usual rule of thumb (pre-pandemic) is to keep $CO_2 < 1000$ ppm for adequate ventilation for the number of people inside.

Good article on portable air cleaners (below)

https://www.consumerreports.org/cro/air-purifiers/buying-guide/index.htm

Materials for Masks (from a Cambridge University study):

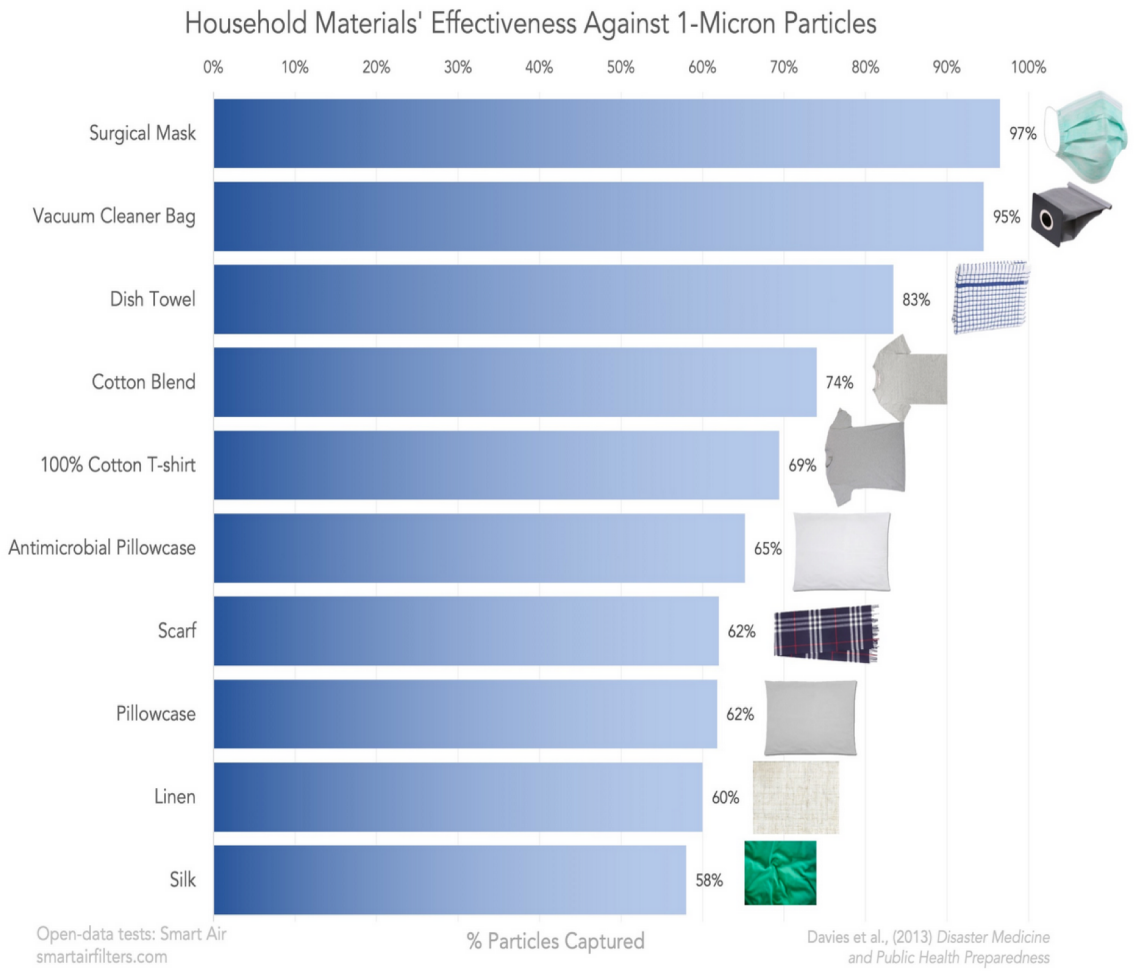
https://smartairfilters.com/en/blog/best-materials-make-diy-face-mask-virus/

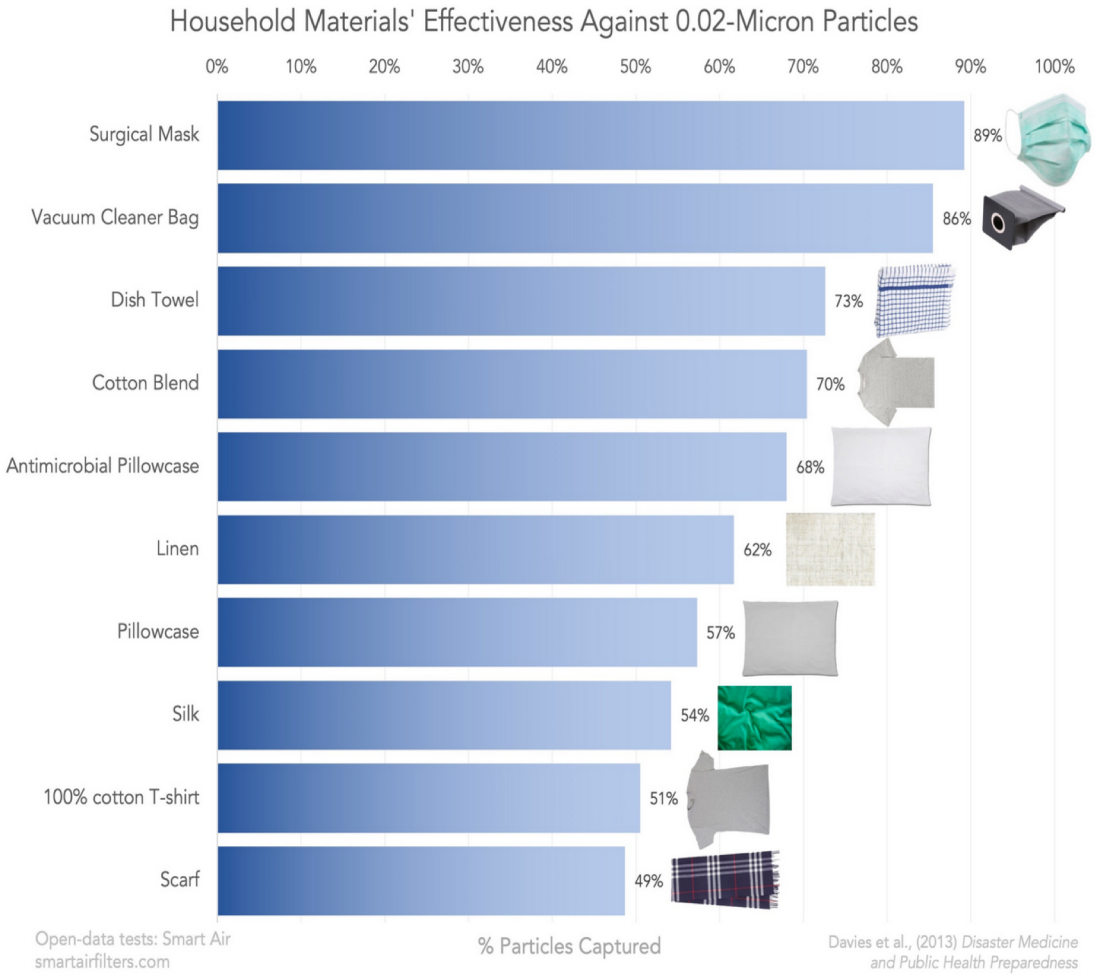
Simple sew yourself mask patterns

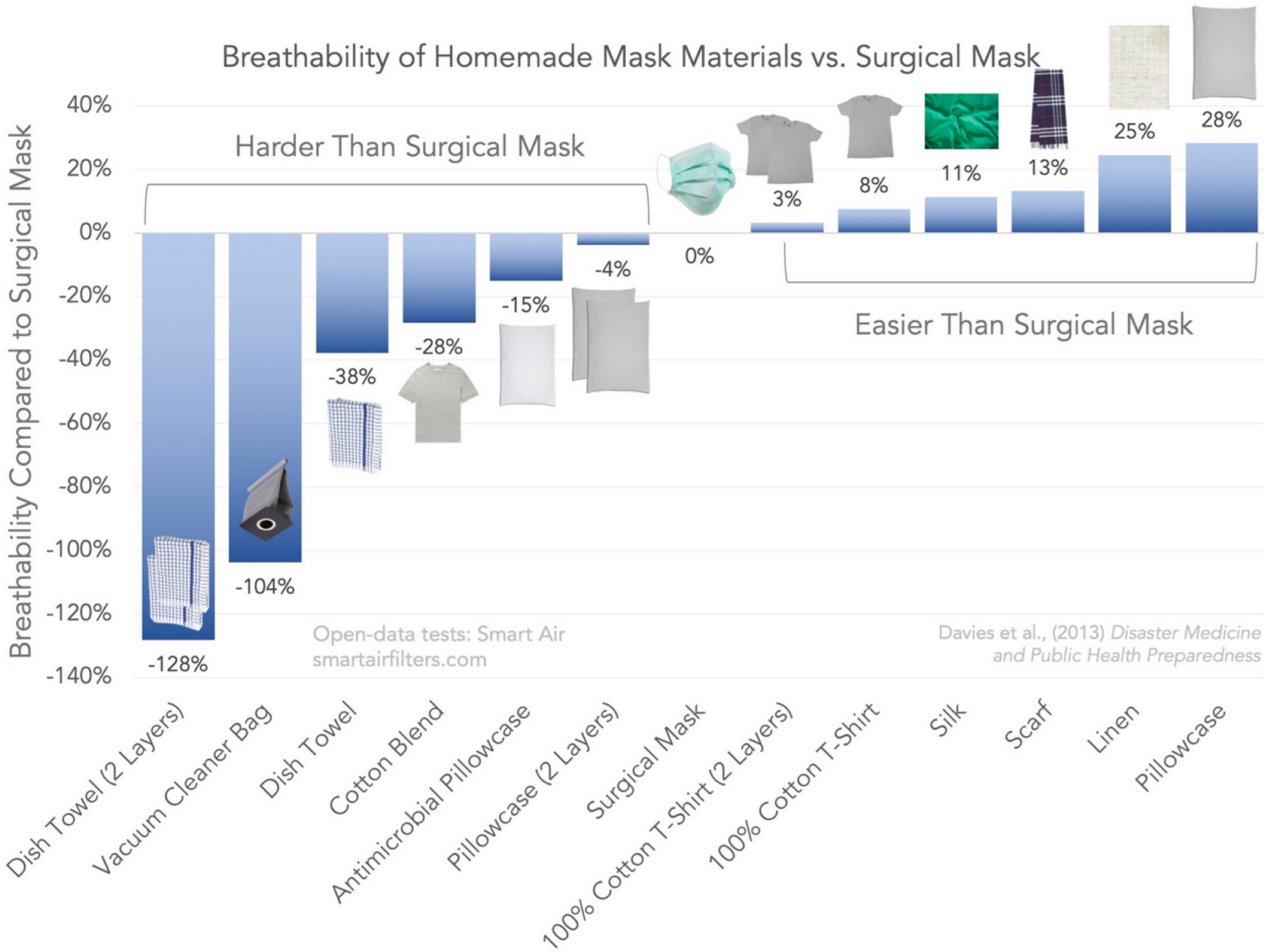
https://masksnow.org/patterns/
https://tinyfleetingsteps.wordpress.com/2020/02/21/492/

Note: you can add filter material into the sleeve of your mask. It will help if the air goes through it and not around it.

Graph from https://smartairfilters.com/en/blog/best-materials-make-diy-face-mask-virus/
Based on: Davis et al. 2013






Breathability of Homemade Mask Materials vs. Surgical Mask
Breathability Compared to Surgical Mask
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
-120%
-140%
Harder Than Surgical Mask
Easier Than Surgical Mask
-128%
-104%
-38%
-28%
-15%
-4%
0%
3%
8%
11%
13%
25%
28%
Open-data tests: Smart Air
smartairfilters.com
Davies et al., (2013) Disaster Medicine and Public Health Preparedness
Dish Towel (2 Layers)
Vacuum Cleaner Bag
Dish Towel
Cotton Blend
Antimicrobial Pillowcase
Pillowcase (2 Layers)
Surgical Mask
100% Cotton T-Shirt (2 Layers)
100% Cotton T-Shirt
Silk
Scarf
Linen
Pillowcase