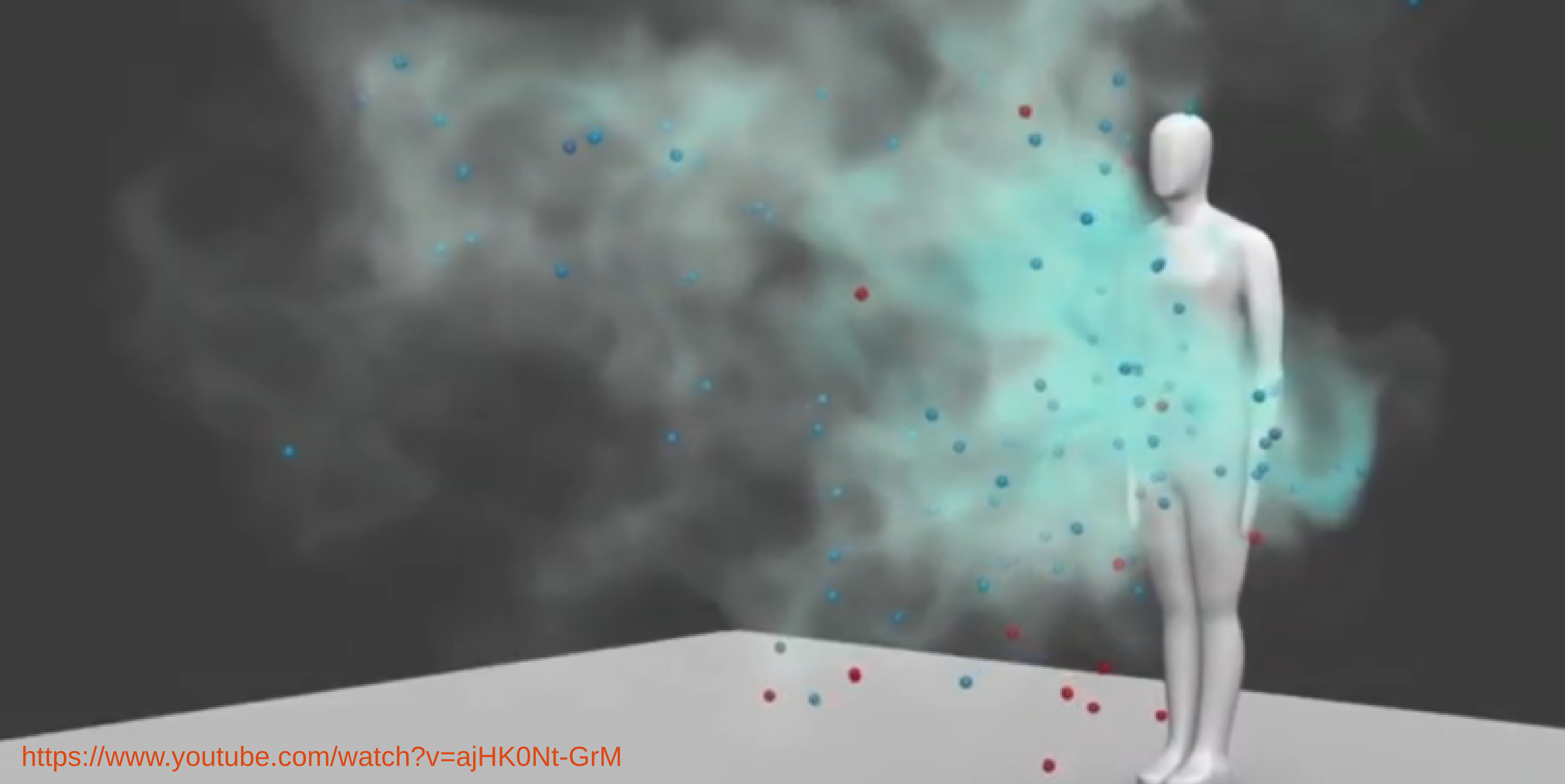
Aerosols: physical phenomena, re-definition and the journey towards health guidance

FINVAC seminar

Prof. Ville Vuorinen, 7/10/2020



https://www.youtube.com/watch?v=ajHK0Nt-GrM

Aerosols: physical phenomena, re-definition and the journey towards health guidance

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Blue d < 10µm → disperse like smoke

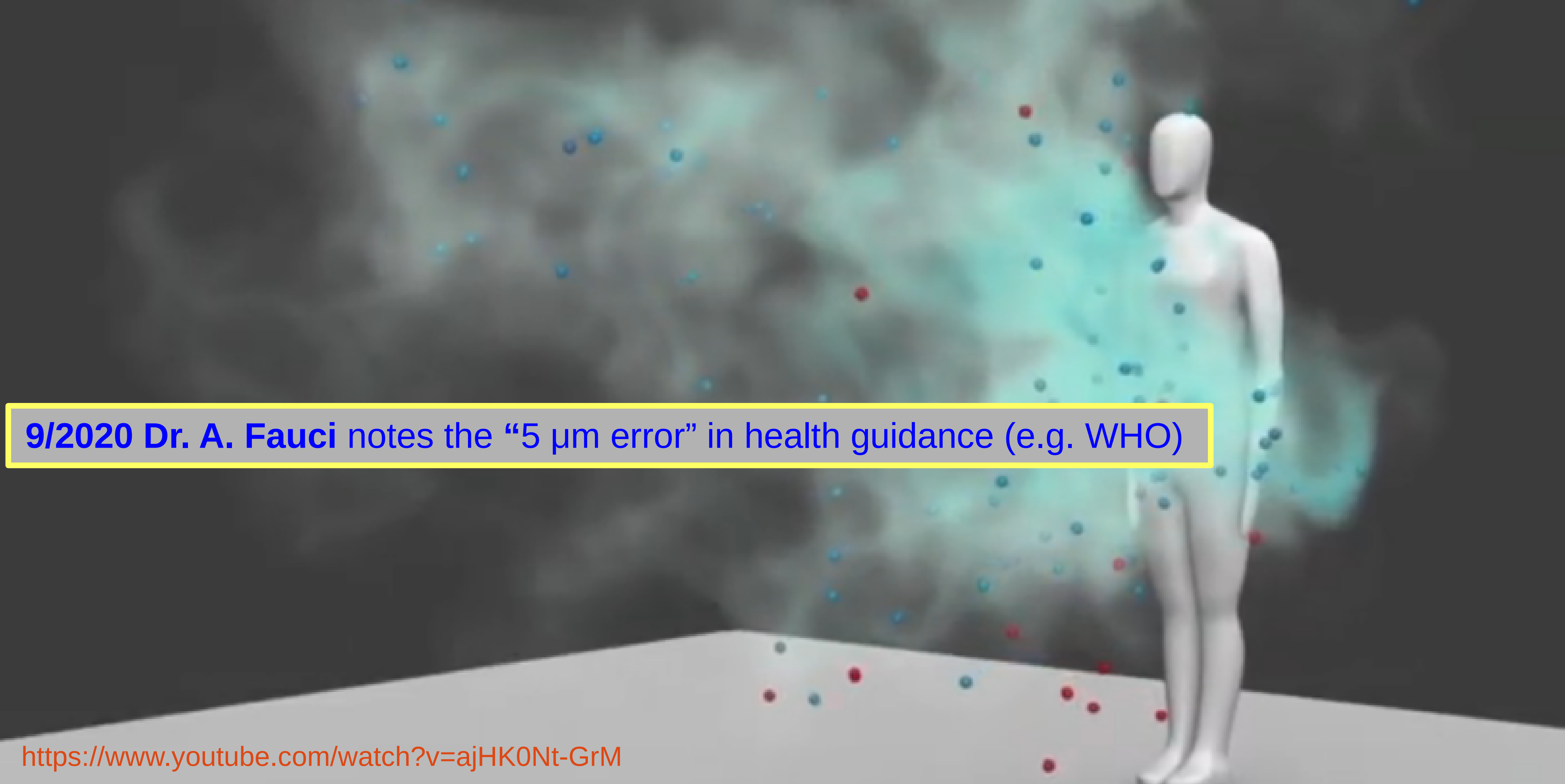
Red 10µm < d < 20µm → start feeling gravity after minutes

https://www.youtube.com/watch?v=ajHK0Nt-GrM

Aerosols: physical phenomena, re-definition and the rough journey towards acceptance

FINVAC seminar

Prof. Ville Vuorinen, 7/10/2020



9/2020 Dr. A. Fauci notes the **“**5 μm error” in health guidance (e.g. WHO)

https://www.youtube.com/watch?v=ajHK0Nt-GrM

ELSEVIER

Safety Science

Available online 11 June 2020, 104866

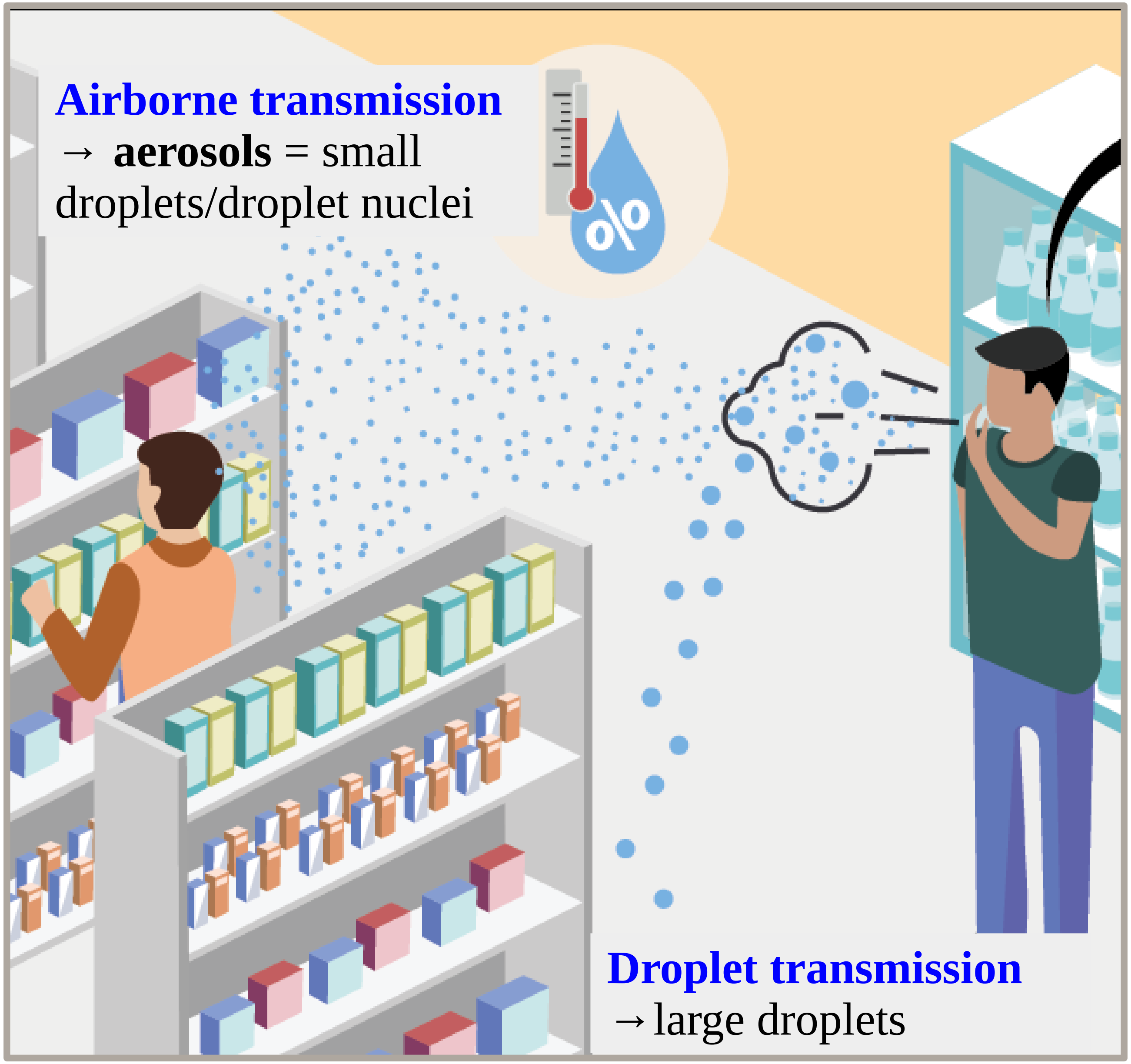
In Press, Journal Pre-proof

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

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

Part 1: Present status on recognition of aerosols as a transmission mode

Small vs large droplets



https://doi.org/10.1016/j.ssci.2020.104866

Asadi et al. (2019)

Aerosol generation:

→ loudness of speaking increases aerosol rate
→ super-emitters emit much more than others

Stadsnytskyi et al. (2020)

Aerosol generation:

→ high variation in patient viral load
→ particles suspended long time e.g. 15min-hours until ventilation removes

Result by Vuorinen et al. on aerosol exposure for mixing ventilation:

We have proposed a theoretical model that explains **average aerosol exposure** by inhalation

Average aerosol concentration (particles/m³) level in a room

Number of persons

Fraction infected

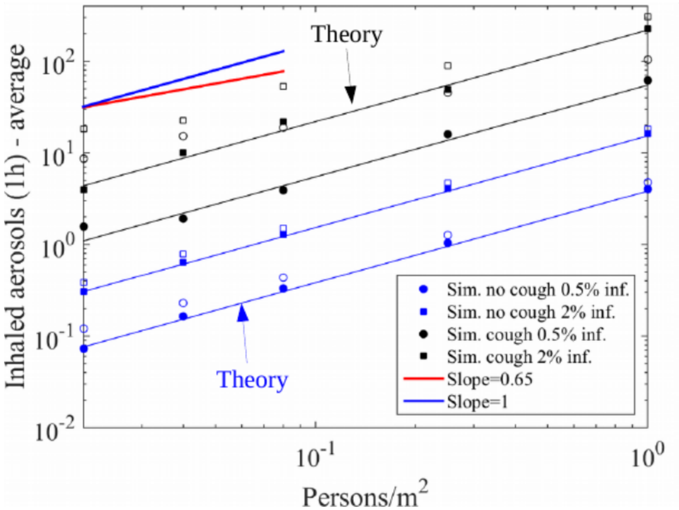
Ventilation (air exchange time)

$$c_{ave} = \frac{qN\tau}{Ah}(\lambda + \lambda_c)$$

Volume

Speaking

Coughing

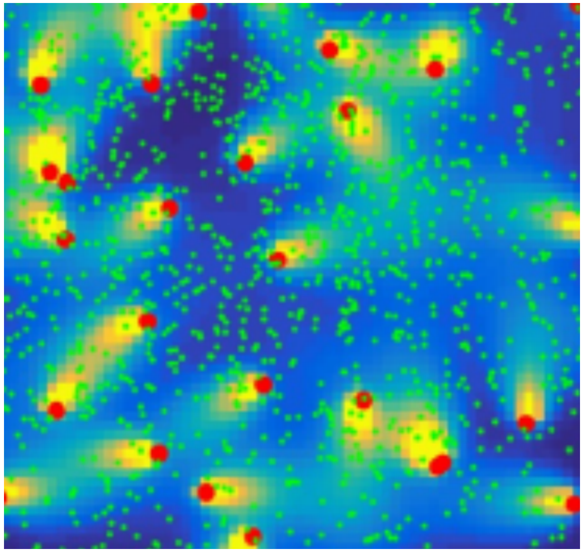


Number of inhaled aerosols for a person during time *t*

$$N_b(t) = c_{ave}\dot{V}_b t$$

Inhalation rate

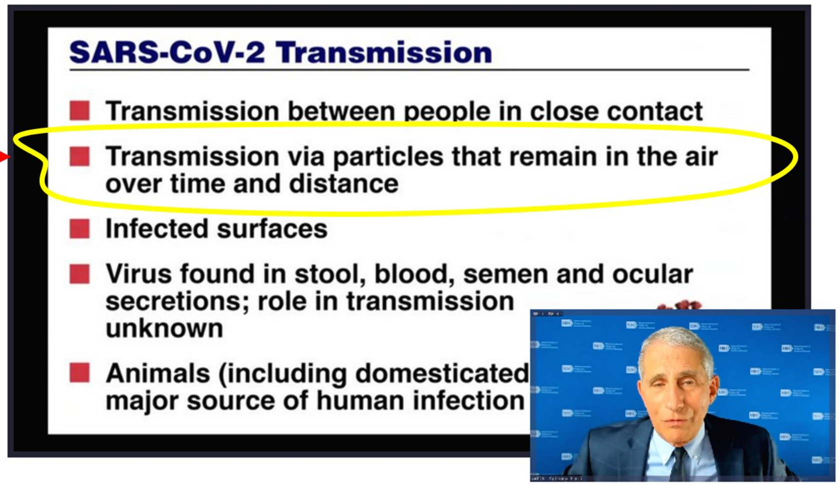
Duration of inhalation



https://doi.org/10.1016/j.ssci.2020.104866

Recent updates on airborne transmission 9/2020

HARVARD
MEDICAL SCHOOL



Fauci 9/2020:
- acknowledges the **huge error in definition of aerosolized particle size**

- acknowledges transmission via particles that remain in the air over time and distance

THE LANCET

Log in

15. Identifying the dominant modes of COVID-19 transmission is an urgent public health priority. There is growing consensus from the aerosol science and infectious disease communities that aerosol inhalation is a key contributor to COVID-19 transmission. The US Centers for Disease Control and Prevention (CDC) and WHO have widely communicated a narrowed scope of possible transmission routes, limited to large droplets expelled by coughs and sneezes, and contact with contaminated surfaces. However, this notion is based on an incorrect assumption that 5 µm particles settle out of the air within 2 m (6 ft). Basic aerosol physics shows that people shed an entire continuum of particles when they cough, sneeze, breathe, or talk. Some of these are very large particles that do settle out of the air quickly because of gravity (influencing the 2 m [6 ft] distancing rule), but the vast majority are smaller particles that stay aloft for between 30 min and several hours, and travel beyond 2 m (6 ft). Mitigating airborne transmission is especially crucial for reducing the risk of superspreader events. These events appear to occur mainly or exclusively indoors, although large outdoor events are often preceded or followed by indoor crowds at bars, pubs, and restaurants.

"THE LANCET" 9/2020:
The **huge error**
in definition of aerosol size (5µm)
acknowledged

Correction: Vuorinen et al. (2020) + NASEM workshop 8/2020:
50-100µm more correct

Recent updates on airborne transmission 10/2020

3. Transmission

The source of the outbreak has yet to be determined. A zoonotic source to the outbreak has not been identified yet, but investigations are ongoing.

SARS-CoV-2 is primarily transmitted between people through respiratory (droplet and aerosol) and contact routes. Transmission risk is highest where people are in close proximity (within 2 metres). Airborne transmission can occur in health and care settings in which procedures or support treatments that generate aerosols are performed. Airborne transmission may also occur in poorly ventilated indoor spaces, particularly if in

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UK and U.S. 10/2020:
- acknowledge **aerosols i.e. airborne transmission** in **poorly ventilated spaces over extended period of time**
- **main mode:** close contact

COVID-19 can sometimes be spread by airborne transmission

- Some infections can be spread by exposure to virus in small droplets and particles that ca to hours. These viruses may be able to infect people who are further than 6 feet away fro or after that person has left the space.
- This kind of spread is referred to as **airborne transmission** and is an important way that measles, and chicken pox are spread.
- There is evidence that under certain conditions, people with COVID-19 seem to have infec than 6 feet away. These transmissions occurred within enclosed spaces that had inadequ infected person was breathing heavily, for example while singing or exercising.
  - Under these circumstances, scientists believe that the amount of infectious smaller produced by the people with COVID-19 became concentrated enough to spread the people who were infected were in the same space during the same time or shortly a had left.
- Available data indicate that it is much more common for the virus that causes COVID-19 t contact with a person who has COVID-19 than through airborne transmission. [1]

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Germans embrace fresh air to ward off coronavirus

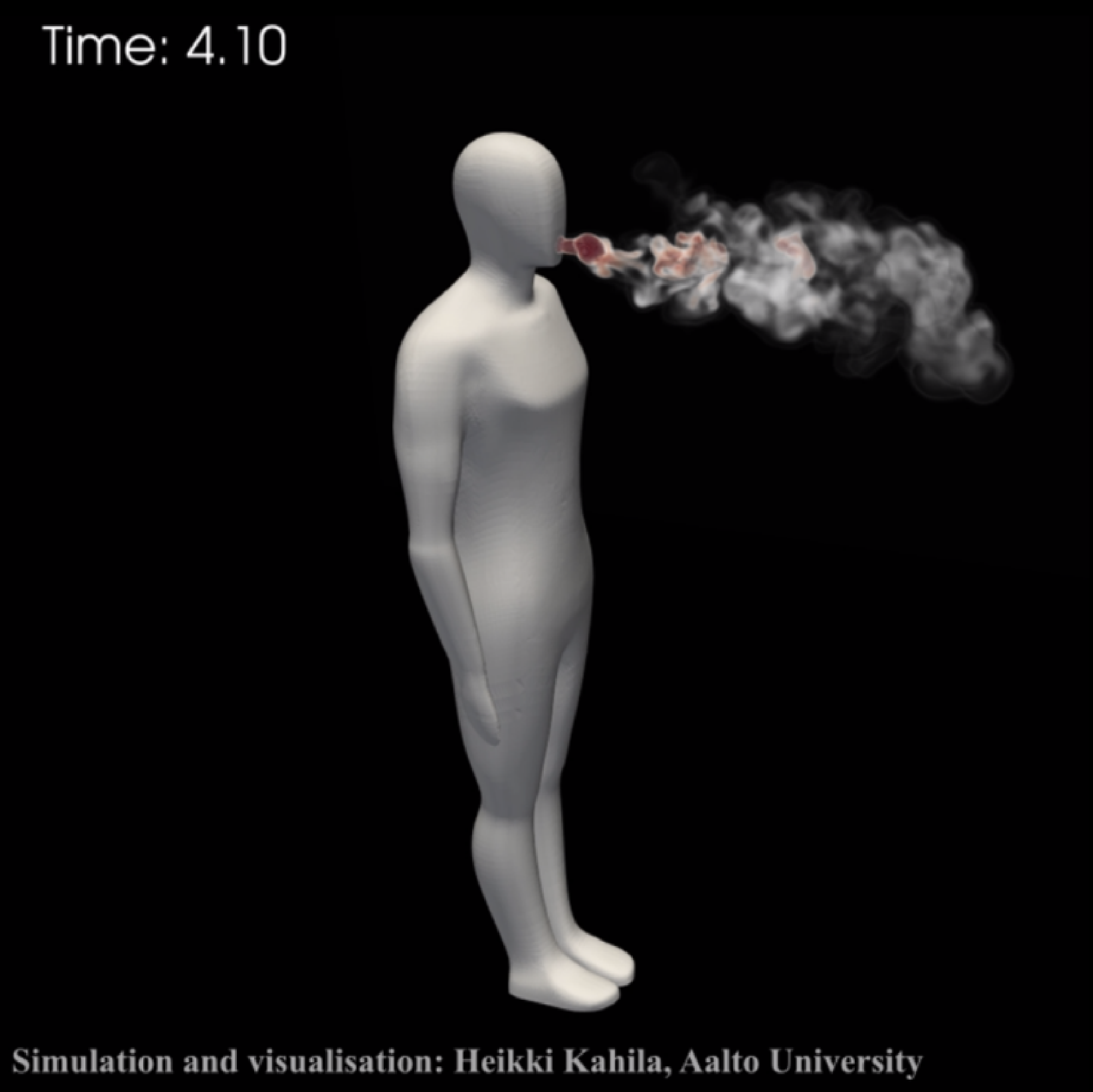
Angela Merkel says ventilation may be one of cheapest and most effective ways of containing virus

- Coronavirus - latest updates
- See all our coronavirus coverage

Merkel 10/2020: fresh air and ventilation may be one of the cheapest and most effective ways to tackle the coronavirus

Part 2: Phenomena

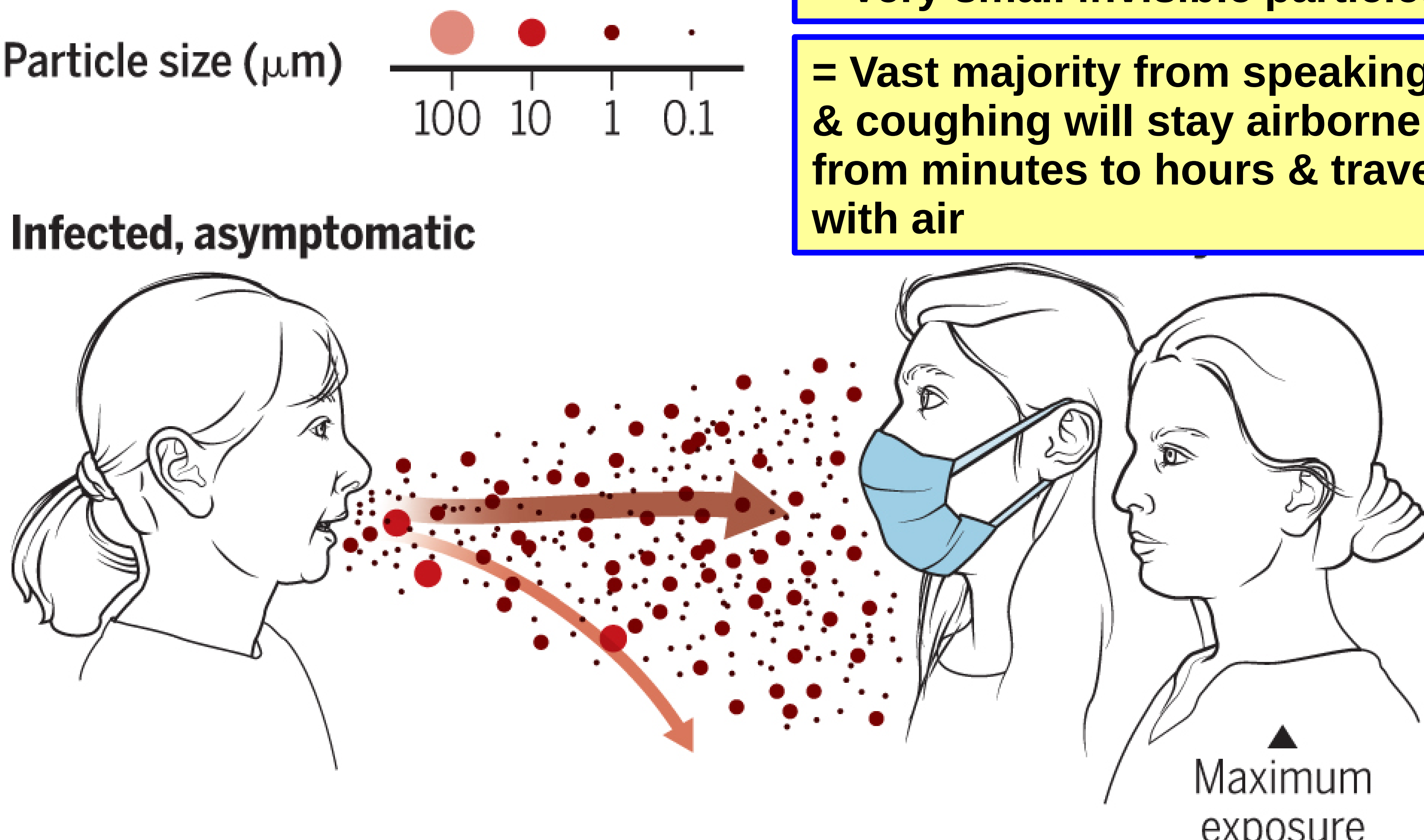
1/4: Air moves and transports the aerosols = small particles that follow the flow – same physics as cigarette smoke



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.

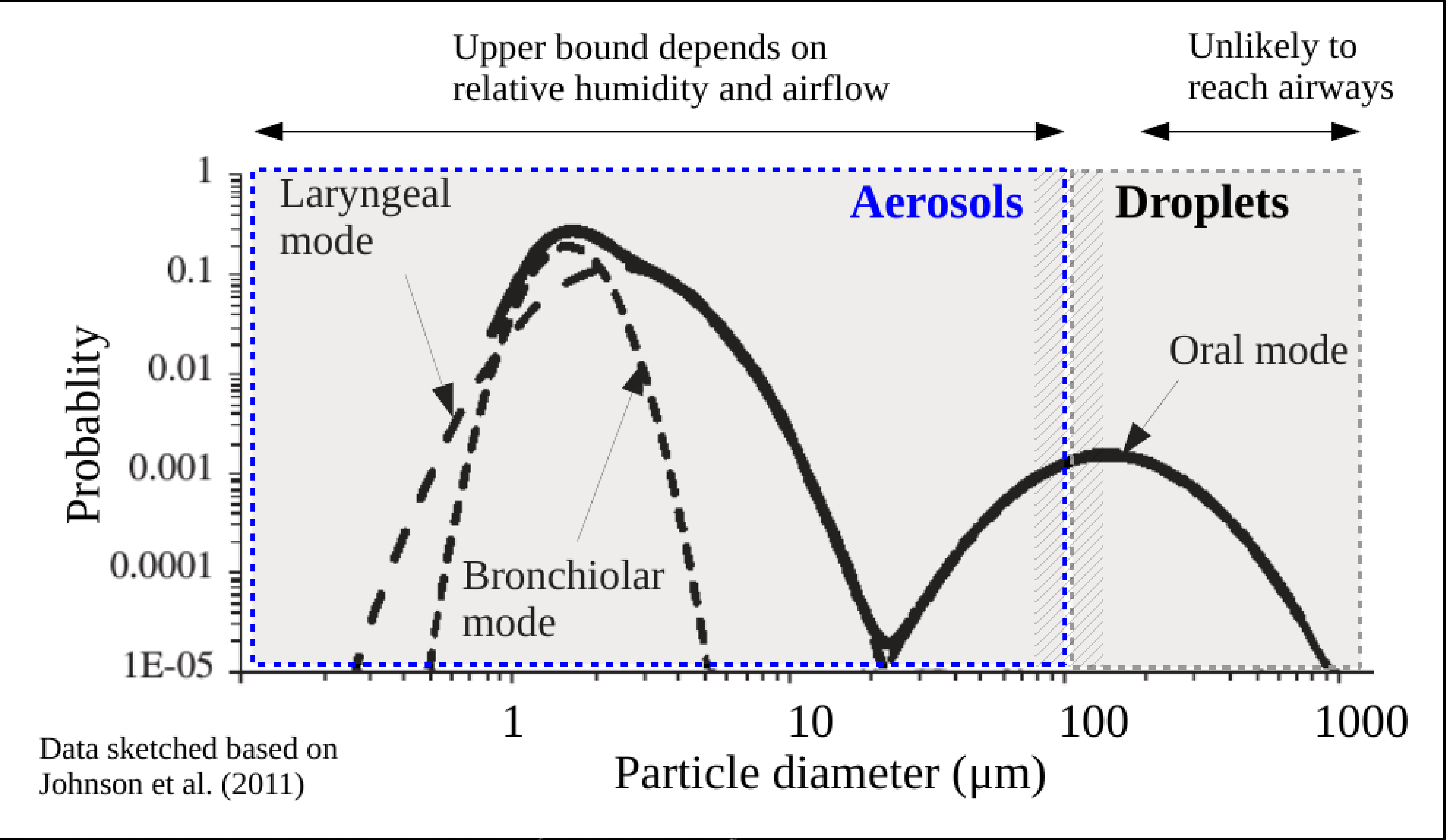
= Very small invisible particles

= Vast majority from speaking & coughing will stay airborne from minutes to hours & travel with air



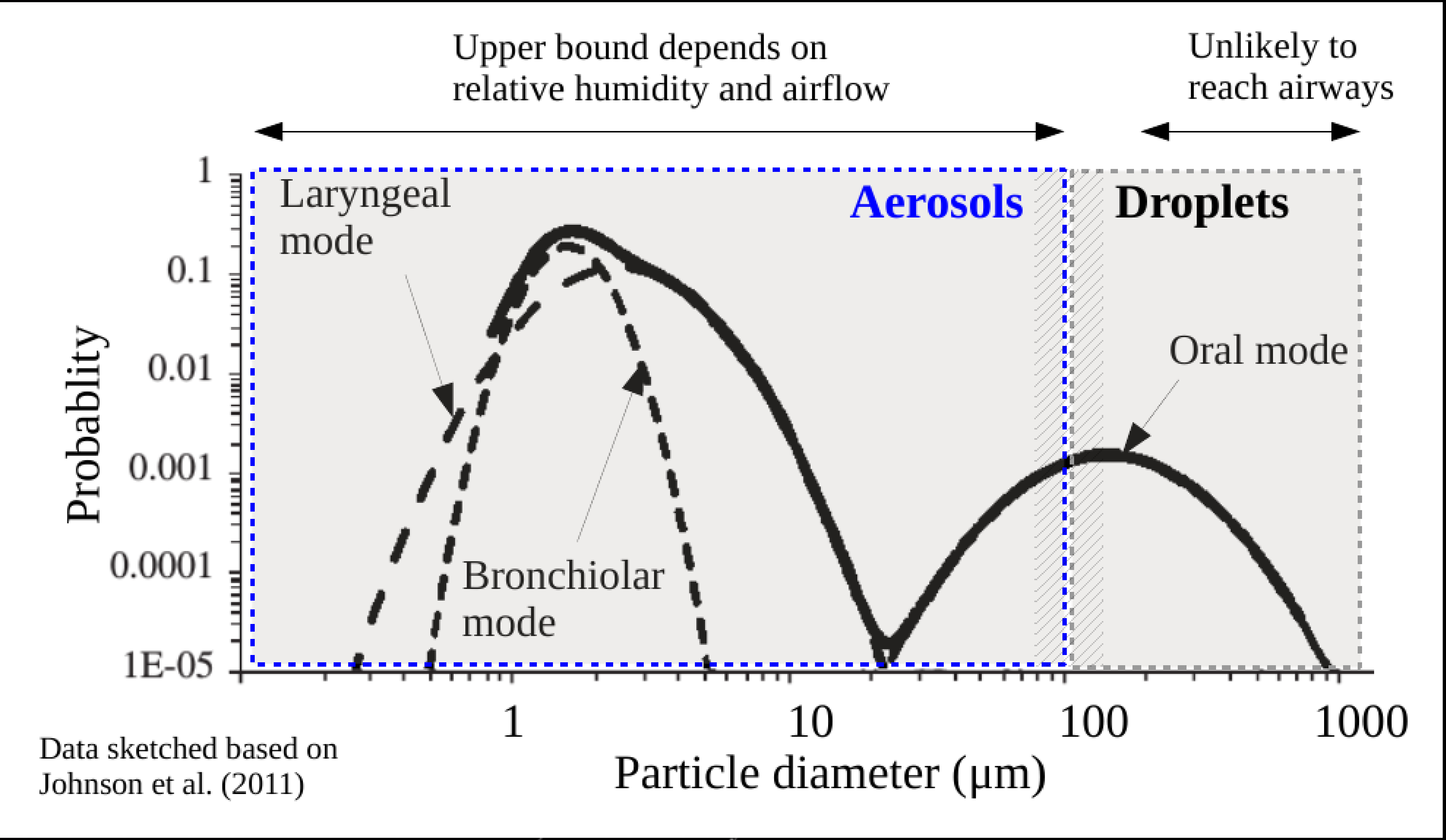
https://science.sciencemag.org/content/368/6498/1422

2/4: Aerosols and droplet size distribution have been measured and well-understood (e.g. Johnson et al. 2011)



2/4: Aerosols and droplet size distribution have been measured and well-understood (e.g. Johnson et al. 2011)

NOTE: 1) viral load may strongly depend on their site of origin in the respiratory tract (may not scale with d^3),
2) evaporation complicates interpretation of figure below.



3/4: "Falling time" for solid particles in still ambient air

EXAMPLE:

CORRECT: d=10 µm solid particle falls down from 1.6m height in approx. 8 minutes in fully still air (airflow neglected)

Particle timescale

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

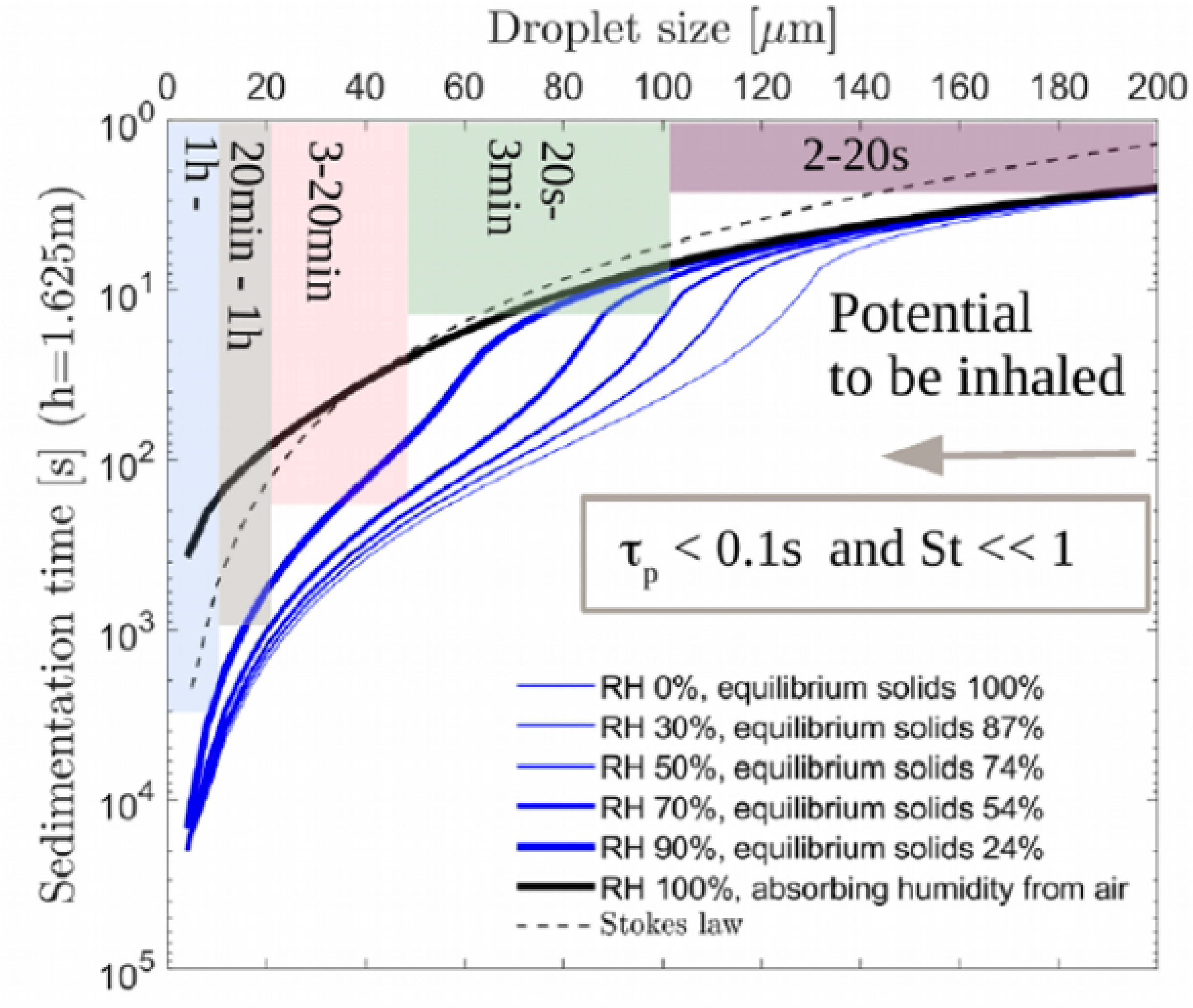
Terminal velocity:

$$v_p = \tau_p g$$

Falling time:

$$t_s = h/v_p$$

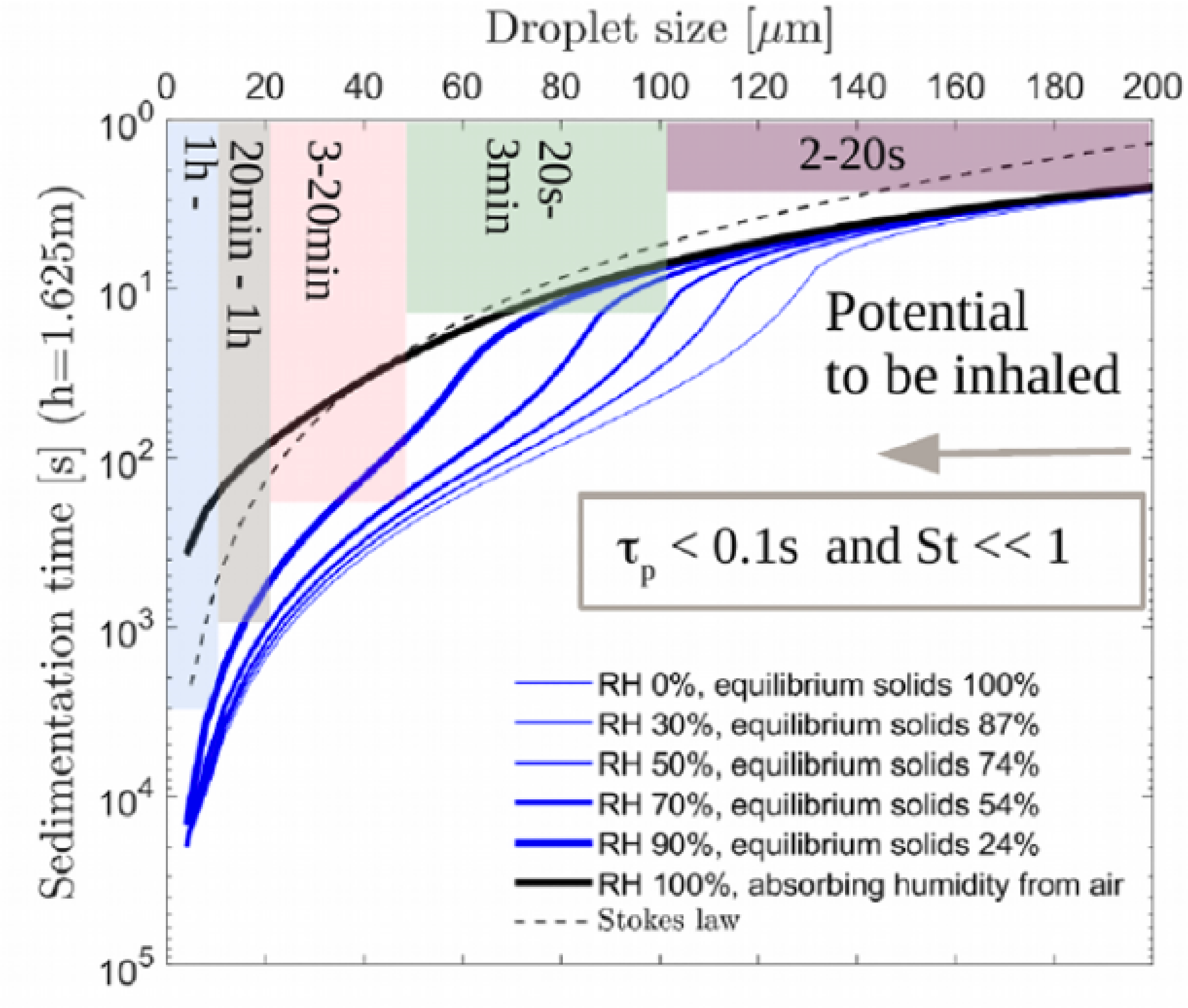
4/4: Droplet falling time and hence virus concentration in the air depend on the relative humidity which affects evaporation rate. **Below:** stagnant air.



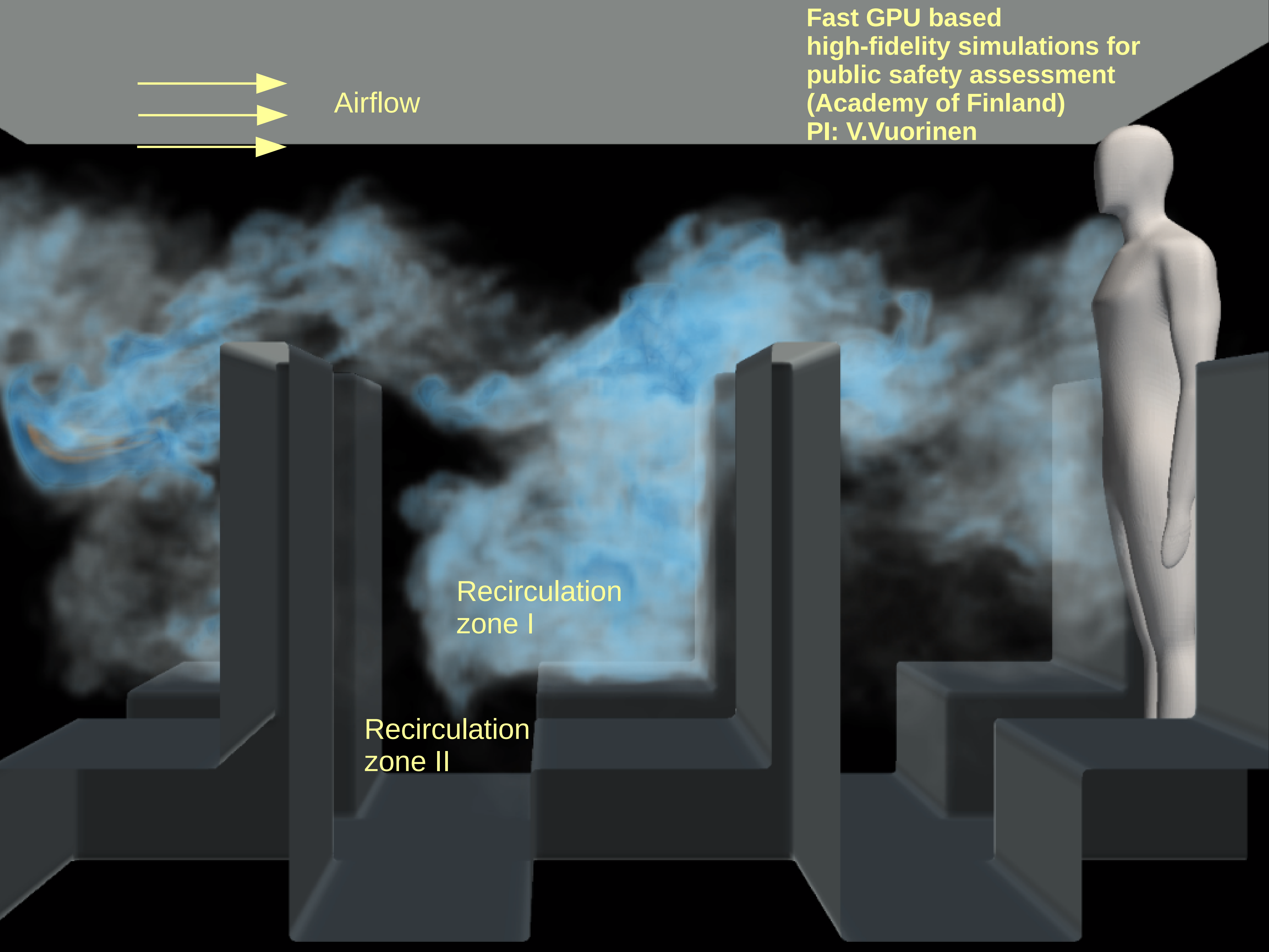
EXAMPLE

In dry air conditions a very large 100 μm droplet could stay in still air **~50 sec.**

In moist air conditions a very large 100 μm droplet could stay in still air **~8 sec.**



Part 3: Outlook and conclusions


Fast GPU based
high-fidelity simulations for
public safety assessment
(Academy of Finland)
PI: V.Vuorinen
Airflow
Recirculation
zone I
Recirculation
zone II

Conclusions

- **AEROSOL:** re-defined to include large portion of large droplets as well
- **AIRBORNE TRANSMISSION:** highly relevant mode
- **BUT:** most commonly short range (shared air), poorly ventilated places, exposure time depends on distance
- **ESSENTIAL SUPPLEMENTARY GUIDANCE URGENTLY NEEDED:**

  ventilation, outdoors better than indoors, masks
- **MOTIVATE PEOPLE:** why social distancing, why avoid crowds, how to decrease personal risk?
- **MULTIDISCIPLINARY:** fluid mechanics, virology, chemistry, medicine, behavioral sciences, HVAC
- **NOTE:** hygiene (e.g. hand/cloth contamination) very important. Possibly as important as inhalation.

Tweet by Finnish government on 28/7/2020