Approche quantitative du risque de transmission de SARS-CoV-2 en voie aérosol

Florian Poydenot, Ismael Abdourahamane, Elsa Caplain, Samuel Der, Antoine Jallon, Inés Khoutami, Amir Loucif, Emil Marinov, Jacques Haiech[a], Alice Lebreton[b], Bruno Andreotti

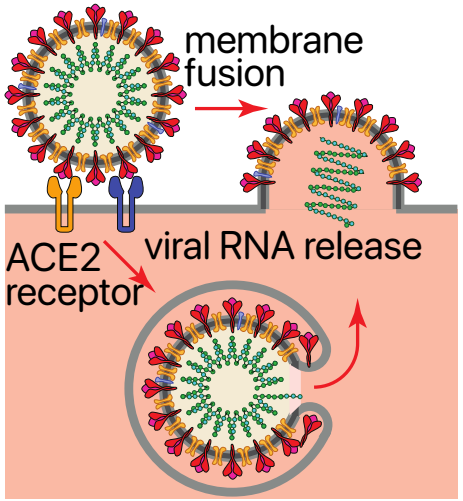
Laboratoire de Physique de l'Ecole Normale Supérieure (LPENS)

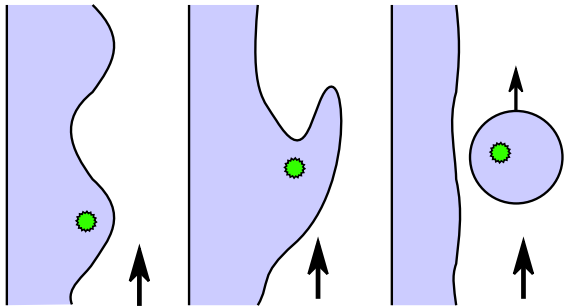
[a]Cogitamus Laboratory/CNRS UMR 7242

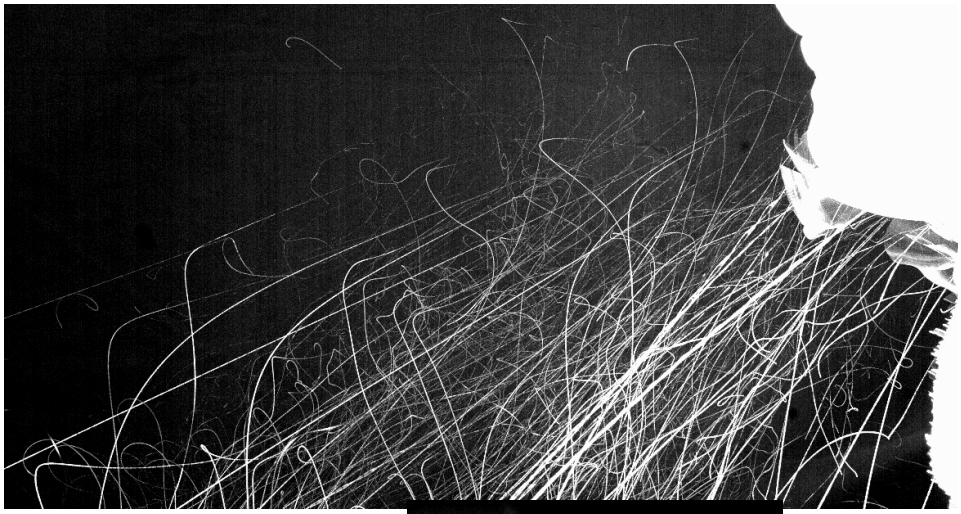
[b]Institut de Biologie de l'ENS (IBENS)-INRAE, Micalis Institute

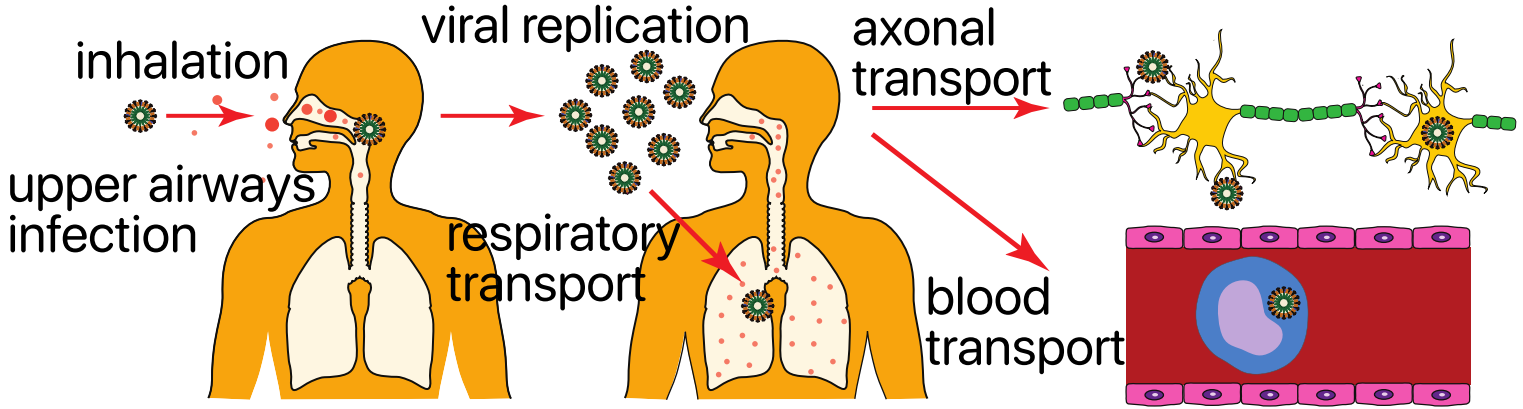
Congrès Général de la SFP, 6 Juillet 2023

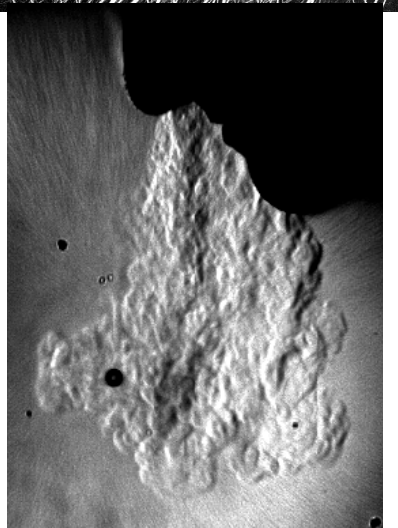
SARS-CoV-2 and COVID-19 transmission



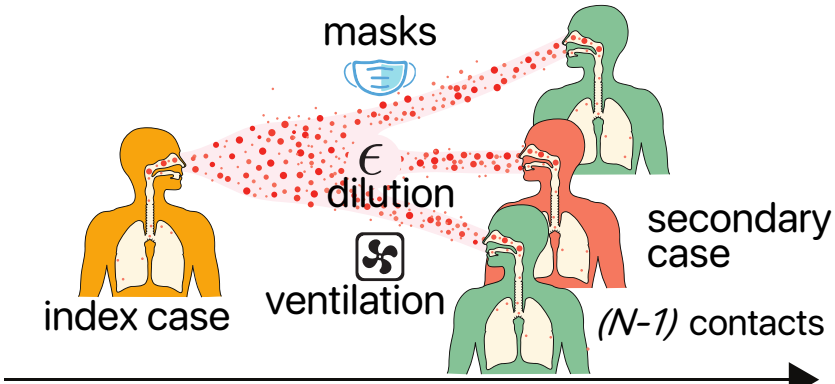


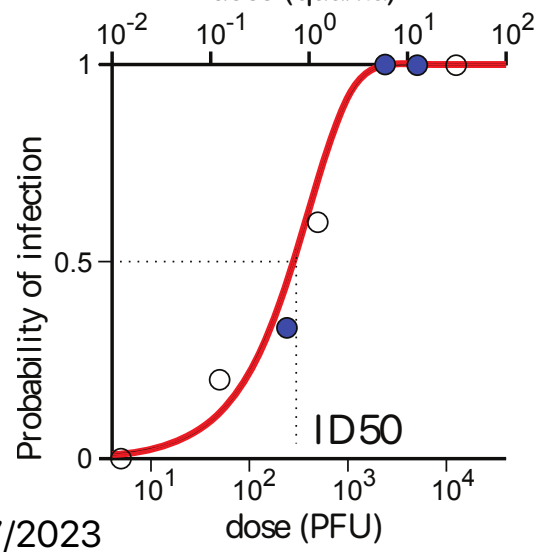


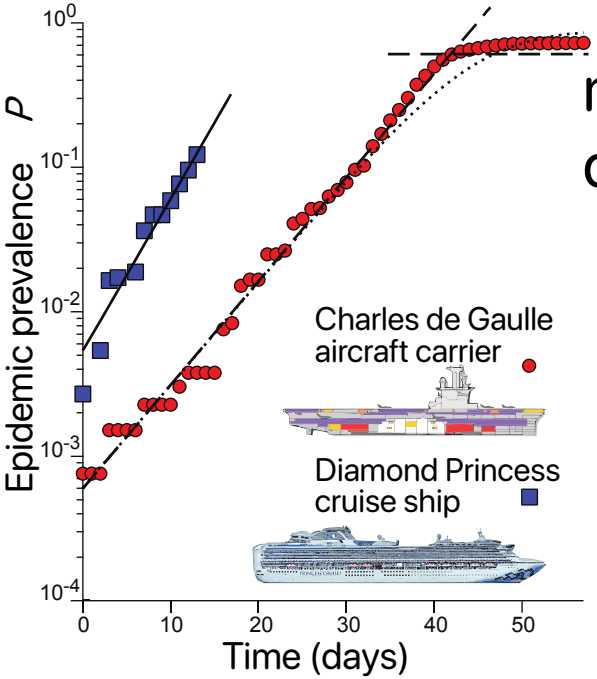




Transmission risk







mean integrated quantum emission $\bar{h}$

original strain	500
Alpha	800
Delta	1500
Omicron BA.1	2800
Omicron BA.2	4700

Poydenot et al., PNAS Nexus 2022
Poydenot et al., Biochimie 2023

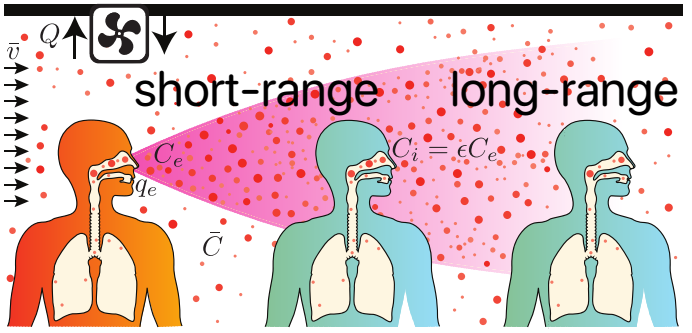
Number of new infections

$$\bar{r} = (N-1)\epsilon\bar{h}$$

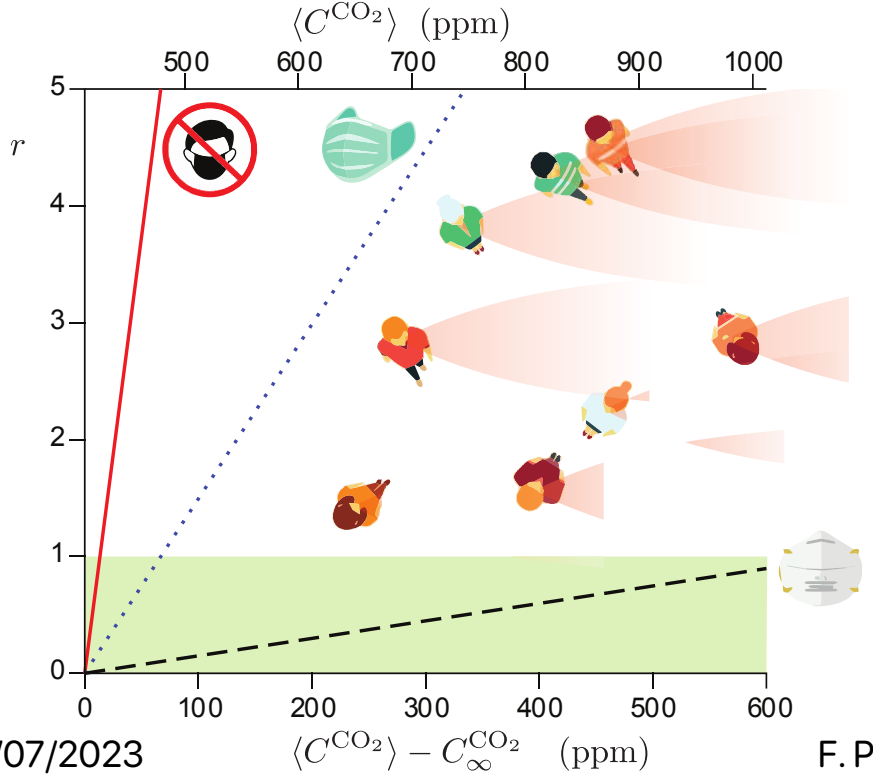
How to quantify the dilution ?

Long and short-range risk

$$\bar{r} = \lambda^2 \frac{\langle C^{\mathrm{CO_2}} \rangle - C_\infty^{\mathrm{CO_2}}}{C_e^{\mathrm{CO_2}}} \bar{h}$$

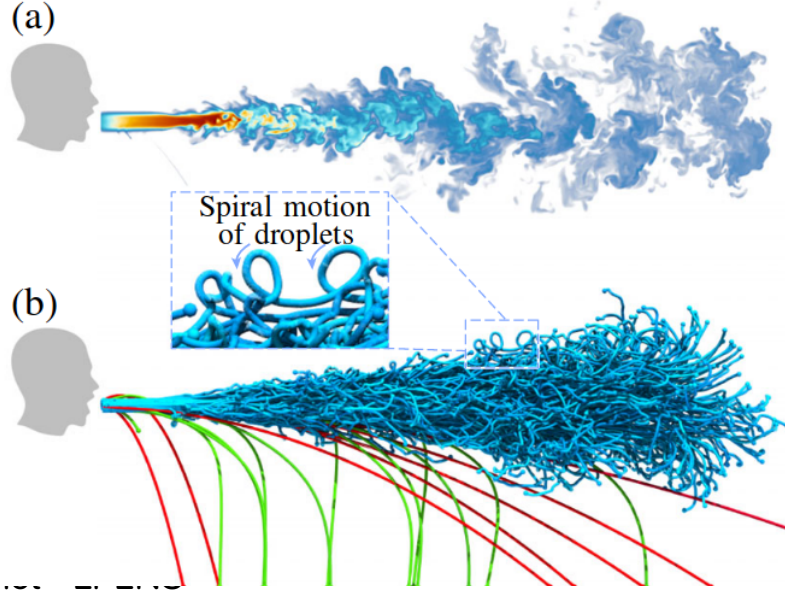


Long-range risk $\langle C^{\mathrm{CO_2}} \rangle$ uniform



Short-range risk

$\langle C^{\mathrm{CO_2}} \rangle$ spatially heterogenous

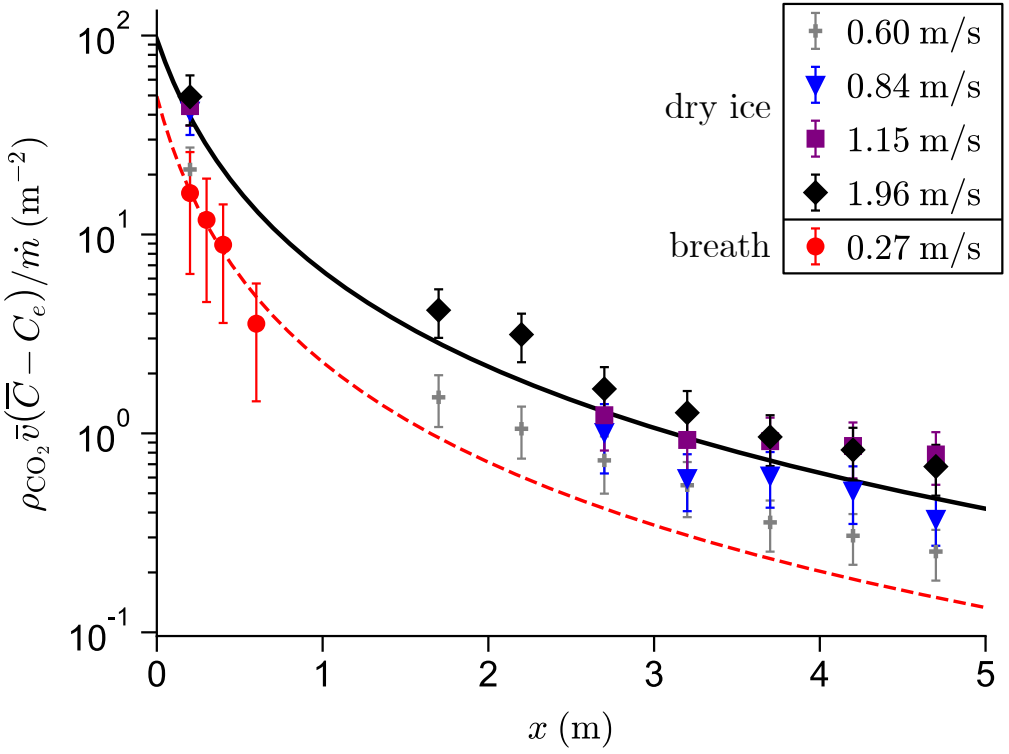


DNS

Chong et al., PRL 2021

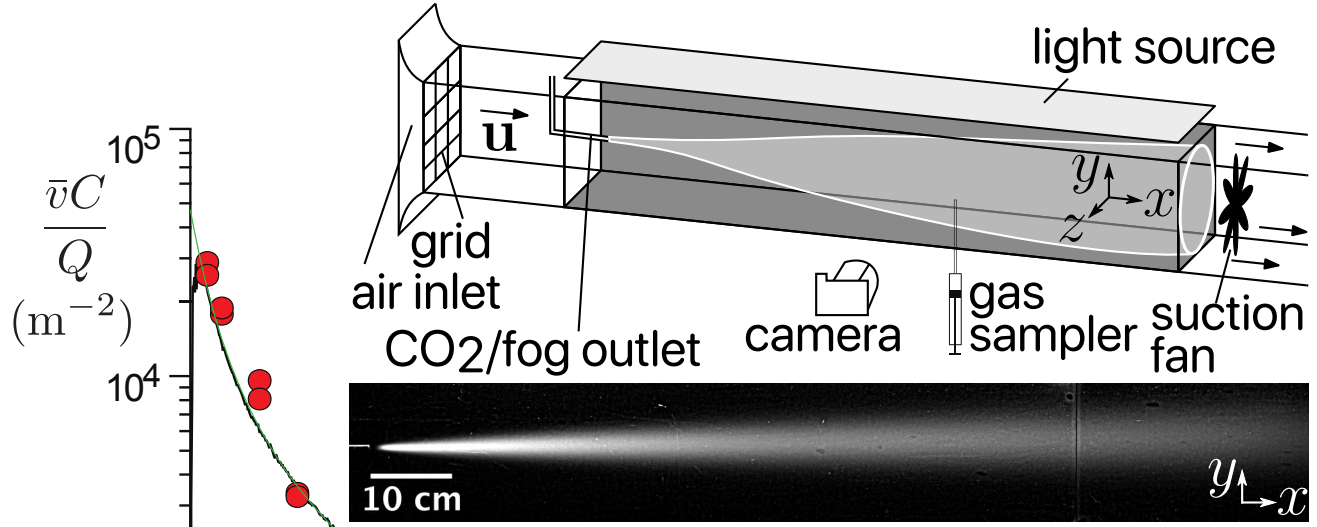
Field experiments

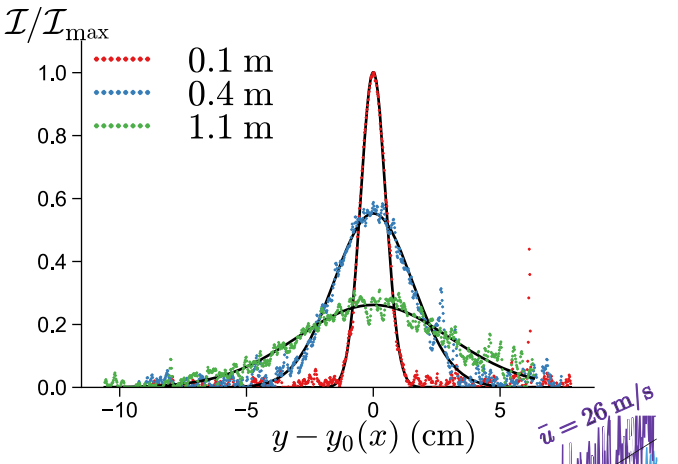
Forum des Halles

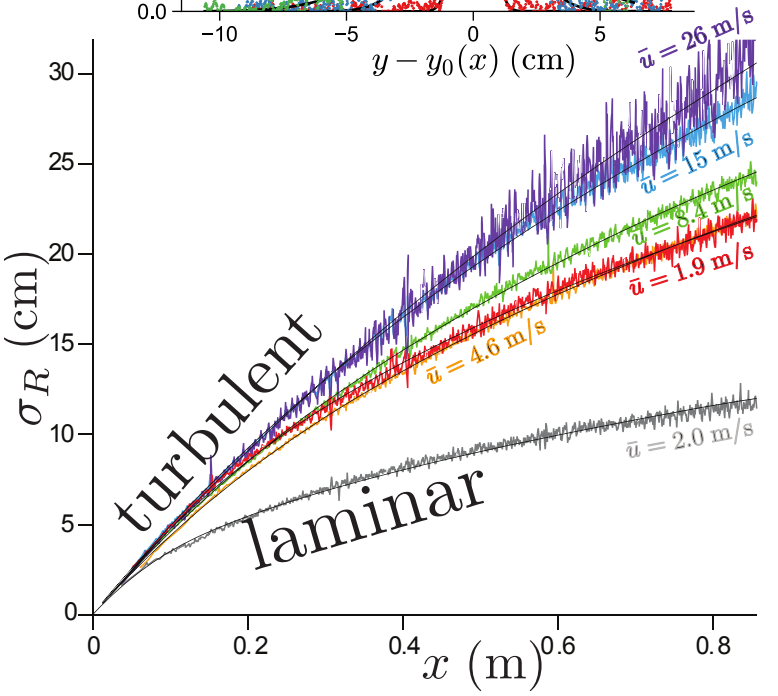


$$\frac{\rho_{CO_2}\,(\overline{C}-C_e)\,\overline{v}}{\dot{m}} = \frac{1}{\alpha^2\,(a+x)^2}$$

Dispersion in a wind tunnel







Poydenot et al., AJP 2022

Lagrangian dispersion

DIFFUSION BY CONTINUOUS MOVEMENTS

By G. I. Taylor.

[Received May 22nd, 1920.—Read June 10th, 1920.]

$$\frac{d\sigma_R^2}{dt} = 2\overline{x(t)v(t)} = 2\int_0^t \overline{v\,(t')\,v(t)}\,\mathrm{d}t'$$

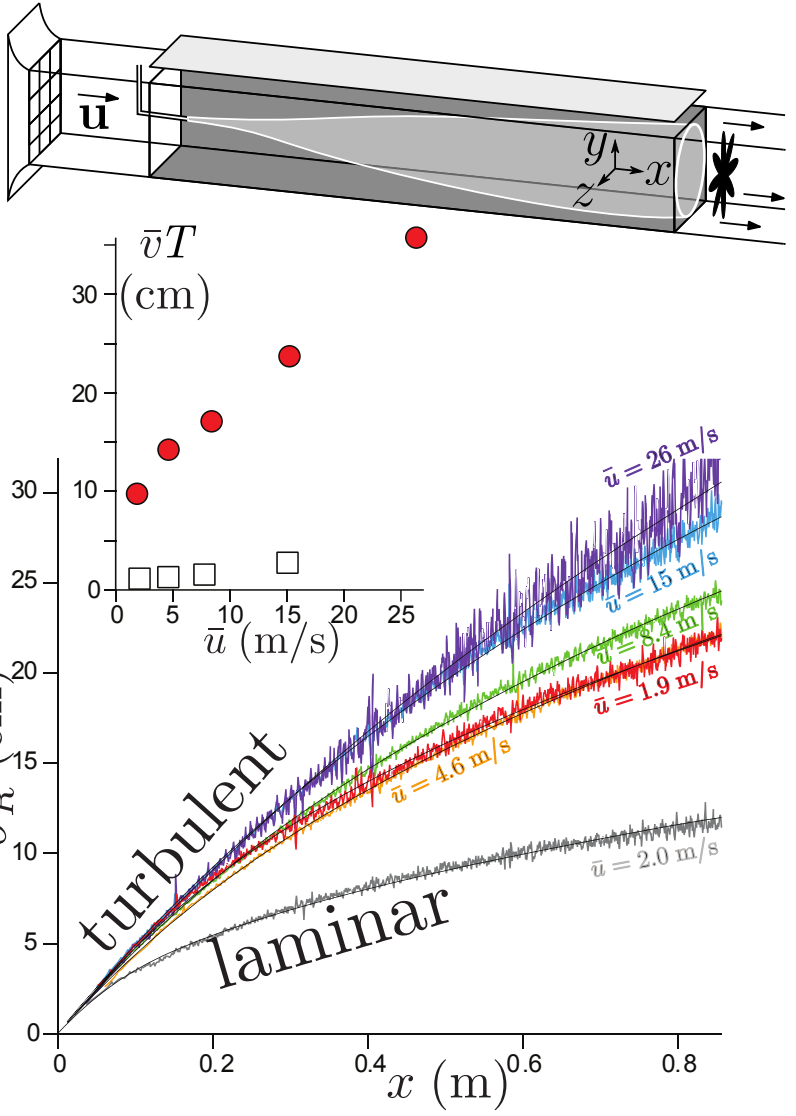
$$\overline{\mathbf{v}'(t)\mathbf{v}'(t+\tau)} = \sigma_V^2 \exp(-\tau/T)$$

Small distance
ballistic regime

$$\sigma_R = \frac{\sigma_V x}{\sqrt{3}\bar{v}}$$

Long distance
diffusive regime

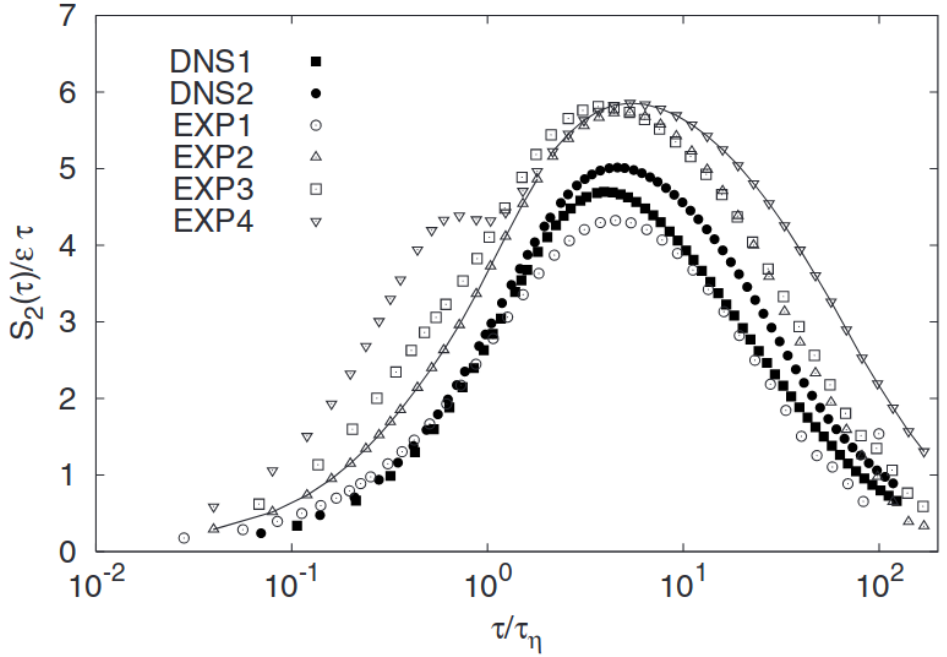
$$\sigma_R = \sigma_V \left(\frac{2Tx}{3\bar{v}}\right)^{1/2}$$



Aerosolization criterion

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{v} = -\frac{1}{\tau_S}(\mathbf{v} - \mathbf{u}[\mathbf{r}]) + \left(1 - \frac{\rho_f}{\rho_p}\right)\mathbf{g} \qquad \tau_S = \frac{\rho_p d^2}{18\eta}$$

No inertial range in Lagrangian structure function:



Kolmogorov-scale Stokes number $\mathrm{St} = \frac{\tau_S}{\tau_K}$

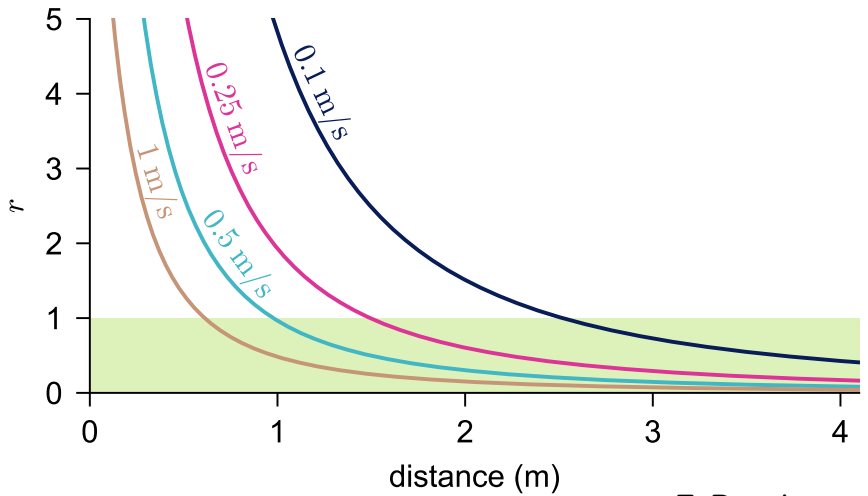
Lagrangian time scale Stokes number $\mathrm{St} = \frac{\tau_S}{T}$

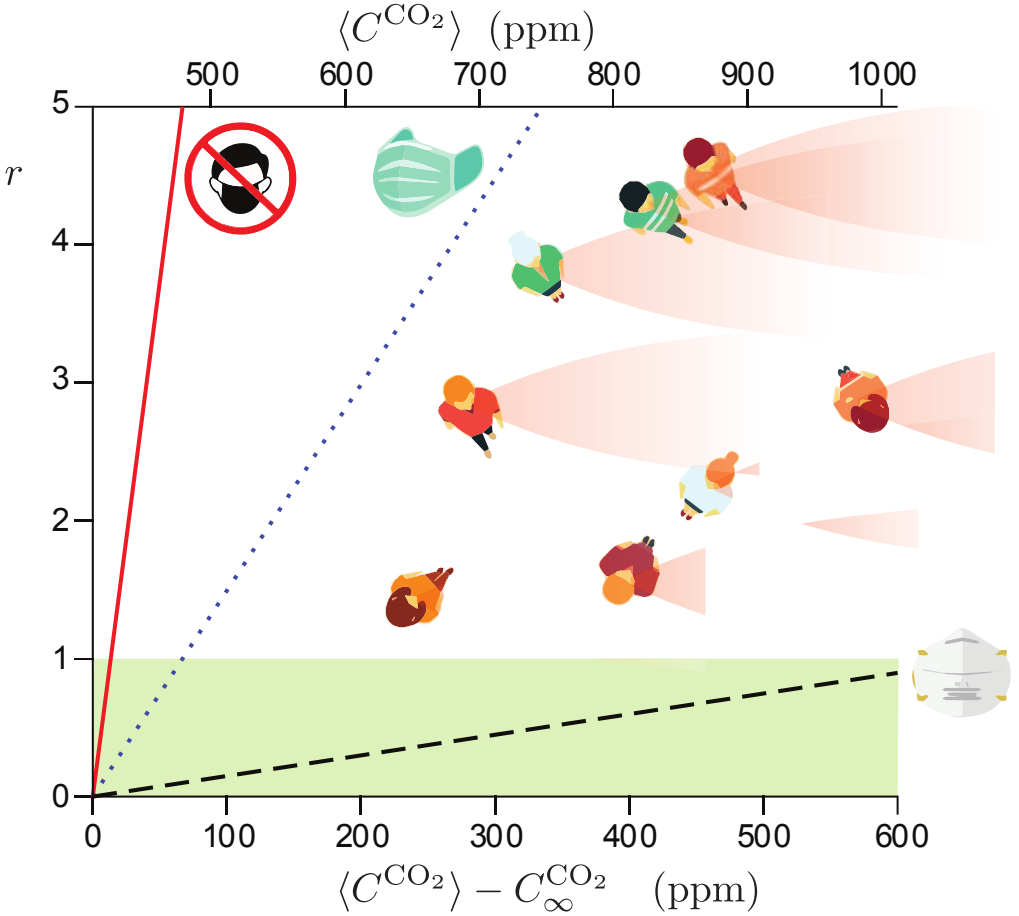
Biferale et al., Phys. Fluids 2008

crossover at 100 µm

Take home messages

- CO2 is a risk proxy both for short- and long-range transmission
- Turbulent particle transport is governed by the Lagrangian time scale of the flow





Infectious quantum calibration