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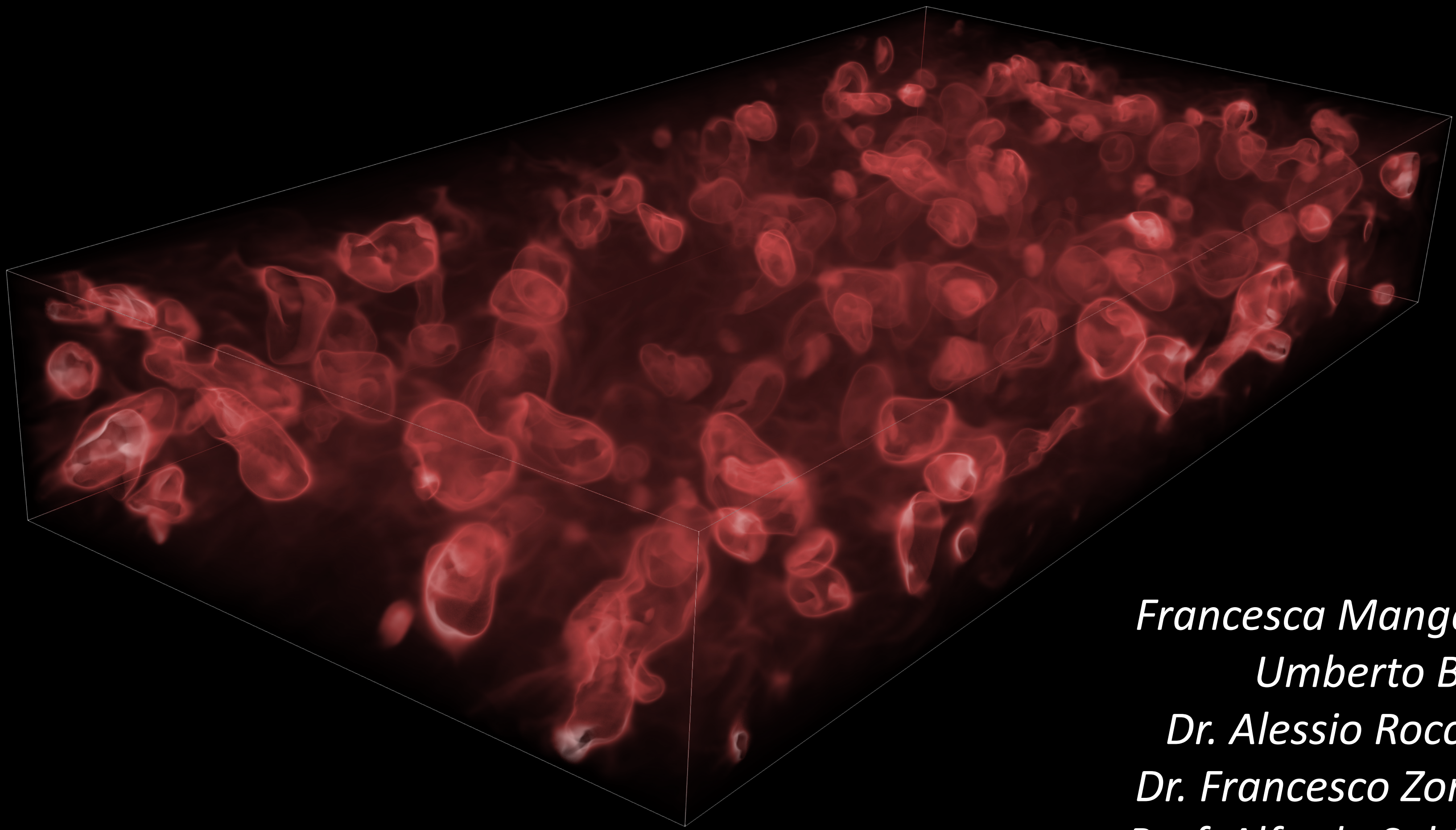
COMETE

Heat Transfer in drop-laden turbulent channel flow



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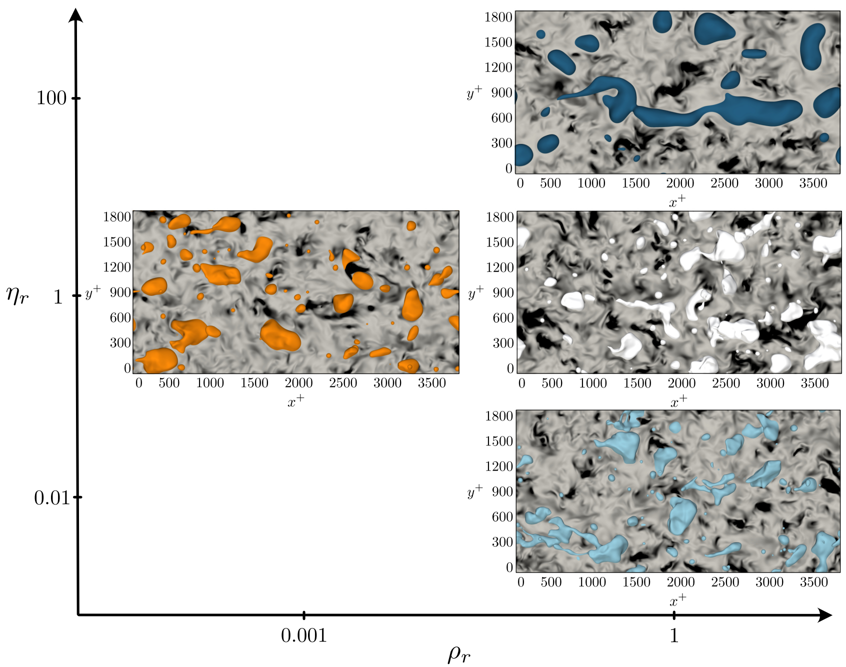
PhD overview

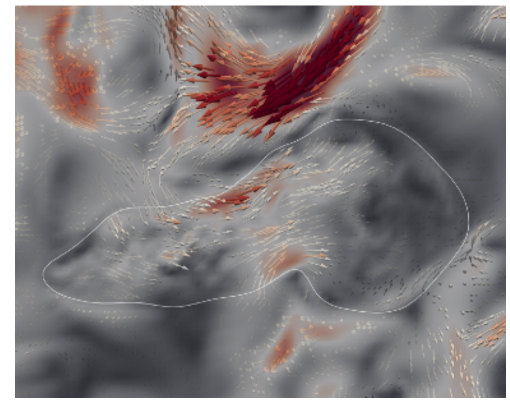
Turbulent flows with drops or bubbles

Effect of density and viscosity ratios



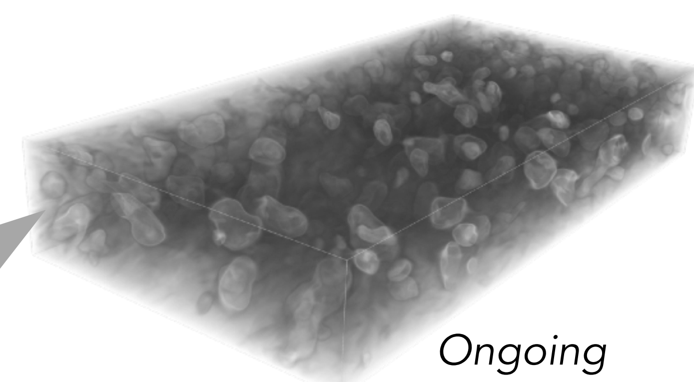
F. Mangani, G. Soligo, A. Roccon & A.Soldati,
"Influence of density and viscosity on deformation, breakage and coalescence of bubbles in turbulence", Phys. Rev. Fluids (2022).

Turbulence characterisation



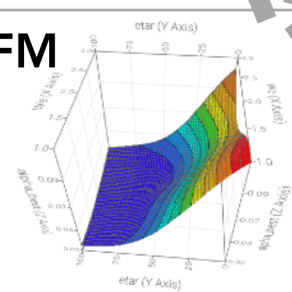
In progress …

Passive scalar (heat)



Ongoing

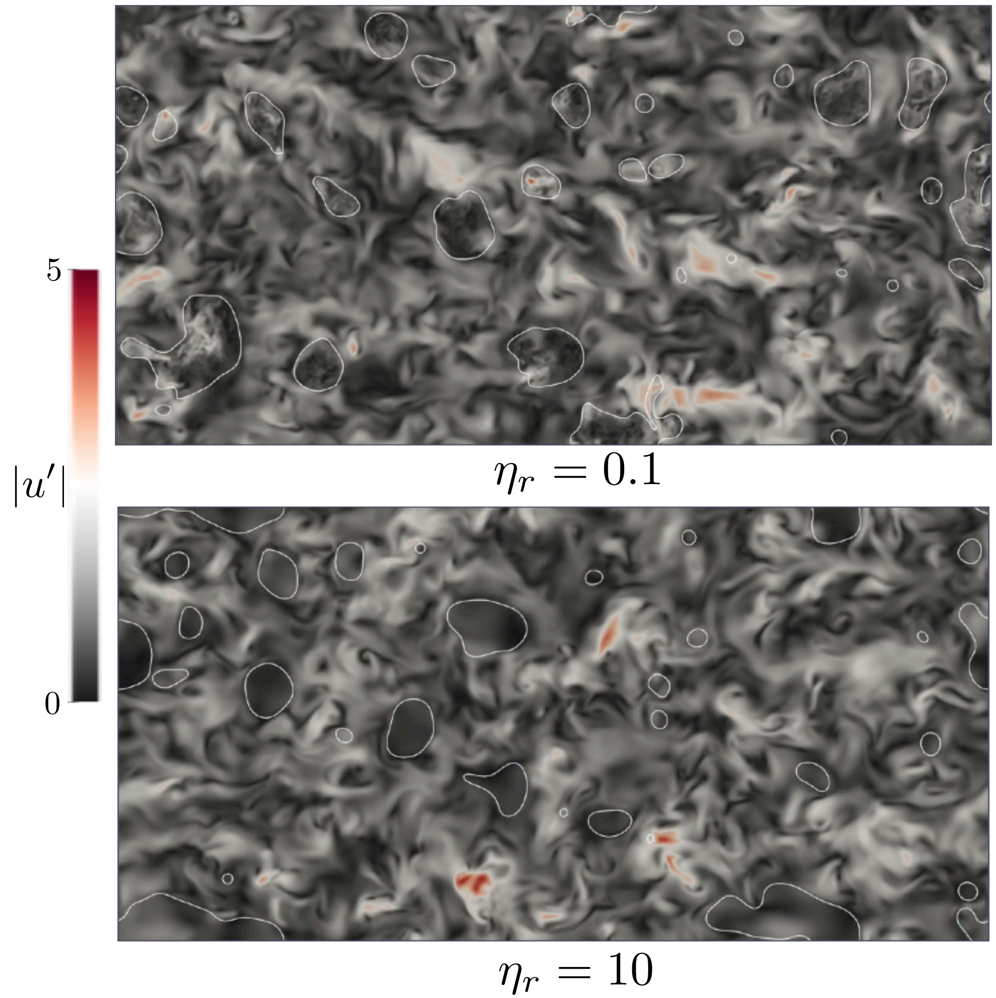
Optimization of PFM correction



Motivation

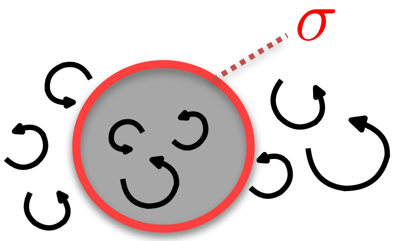
Environmental and industrial applications

Our curiosity



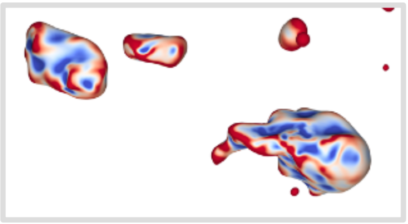
Methodology

Drops dynamics

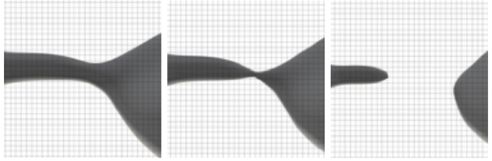


Heat dynamics

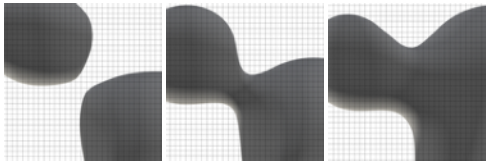
Deformation



Breakup



Coalescence



Passive scalar

Hp: small $\Delta\theta$

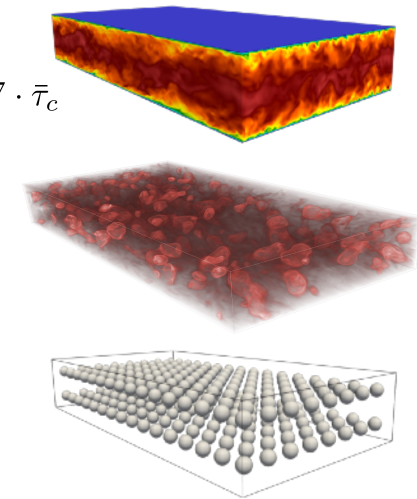
- no thermal dissipation
- no buoyancy
- no thermocapillary forces
- no evaporation/condensation
- constant properties

Methodology: DNS + PFM

Numerical approach

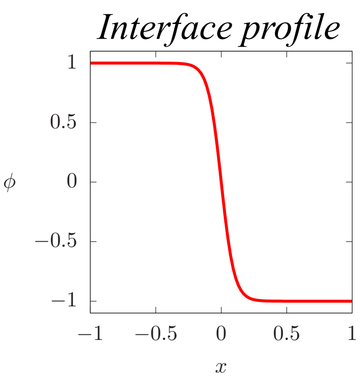
DNS + PFM

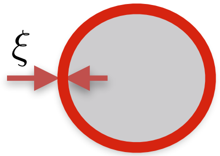
$$\begin{cases} \nabla \cdot \mathbf{u} = 0 \\ \rho(\phi,\rho_r)\left(\dfrac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) = -\nabla p + \dfrac{1}{Re_\tau}\nabla\cdot[\eta(\phi,\eta_r)(\nabla\mathbf{u}+\nabla\mathbf{u}^T)] + \dfrac{3}{\sqrt{8}}\dfrac{Ch}{We}\nabla\cdot\bar{\tau}_c \\ \dfrac{\partial T}{\partial t} + \mathbf{u}\cdot\nabla T = \dfrac{1}{Re_\tau Pr}\nabla^2 T \\ \dfrac{\partial \phi}{\partial t} + \mathbf{u}\cdot\nabla\phi = \dfrac{1}{Pe}\nabla^2\mu + f_p \end{cases}$$



Phase field method

$$\phi = \begin{cases} +1 & \text{Dispersed phase} \\ 0 & \text{Interface} \\ -1 & \text{Carrier phase} \end{cases}$$





$$Ch = \frac{\xi}{h}$$

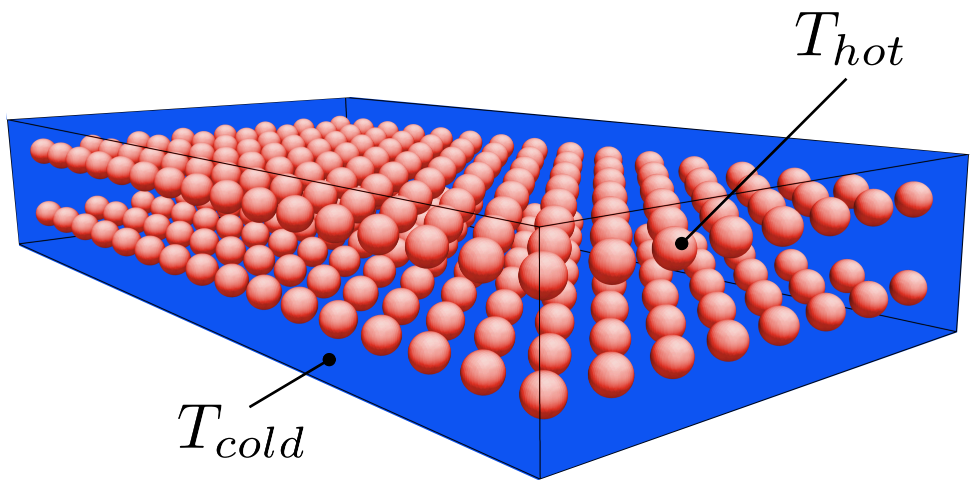
Dimensionless numbers

$$Re_\tau = \frac{\rho_c u_\tau h}{\eta_c} \qquad We = \frac{\rho u_\tau^2 h}{\sigma} \qquad Pr = \frac{\nu}{\alpha}$$

D. Jacqmin, *Calculation of two-phase Navier–Stokes flows using phase-field modeling*, J. Comput. Phys. (1999).
V. Badalassi et al., *Computation of multiphase systems with phase field models*, J. Comput. Phys. (2003).

Methodology
initial/boundary conditions

Focus: heat transfer between drops and carrier flow



Initial conditions

- T : constant temperature
- ϕ : 256 bubbles, volume fraction : $\Phi = 5.4\%$
- $\mathbf{u}$: fully developed turbulent velocity field

Boundary conditions

- T : no flux (adiabatic) + periodic
- ϕ : no flux + periodic
- $\mathbf{u}$: no slip + periodic

Methodology: dual grid

Kolmogorov scale

$$Re_\tau = 300 \rightarrow \begin{array}{l} \eta_{k\,max} \simeq 4.19 \\ \eta_{k\,min} \simeq 1.48 \end{array}$$

Grid cell

$$\Delta x^+ \simeq 3.68$$
$$\Delta y^+ \simeq 3.68$$
$$\Delta z^+_{max} \simeq 1.84$$
$$\Delta z^+_{min} \simeq 0.006$$

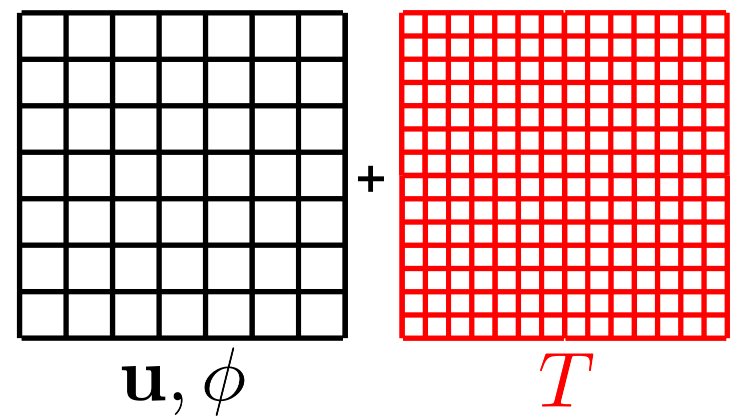
$Pr \rightarrow$

$$\eta_B = \frac{\eta_k}{\sqrt{Pr}}$$

Batchelor scale

Pr	η_B	
1	η_k	*grid 1*
2	$0.71\eta_k$	*grid 1*
4	$0.50\eta_k$	*grid 2*
8	$0.35\eta_k$	*grid 2*

dual grid approach



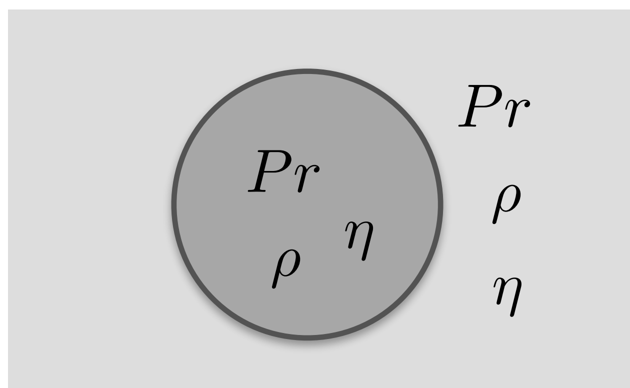
Saved computational time

More than 30%

G. K. Batchelor, I. D. Howells, A. A. Townsend,
Small-scale variation of convected quantities like temperature in turbulent fluid.
J. Fluid. Mech (1959).

Simulation parameters

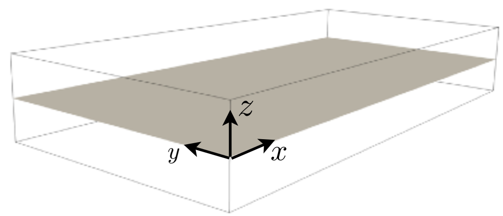
System	Re_τ	We	Pr	$N_x \times N_y \times N_z$ (NS+CH)	$N_x \times N_y \times N_z$ (Energy)
Drop-laden	300	3.0	1.0	$1024 \times 512 \times 513$	$1024 \times 512 \times 513$
Drop-laden	300	3.0	2.0	$1024 \times 512 \times 513$	$1024 \times 512 \times 513$
Drop-laden	300	3.0	4.0	$1024 \times 512 \times 513$	$2048 \times 1024 \times 513$
Drop-laden	300	3.0	8.0	$1024 \times 512 \times 513$	$2048 \times 1024 \times 513$



$$Pr = \frac{\nu}{\alpha}$$

$$Pr \uparrow \quad \alpha \downarrow$$

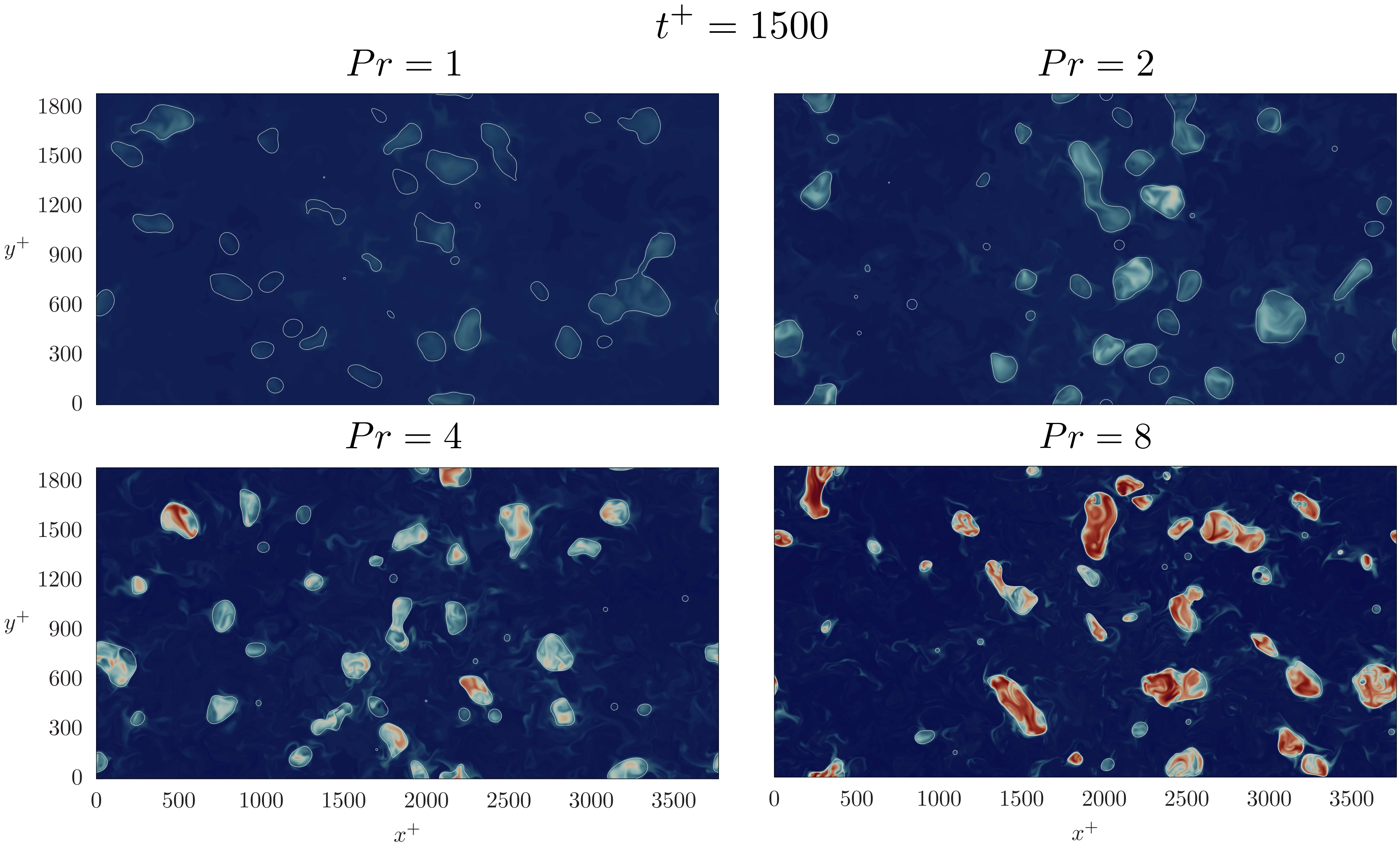
Qualitative results



$Pr = 1$

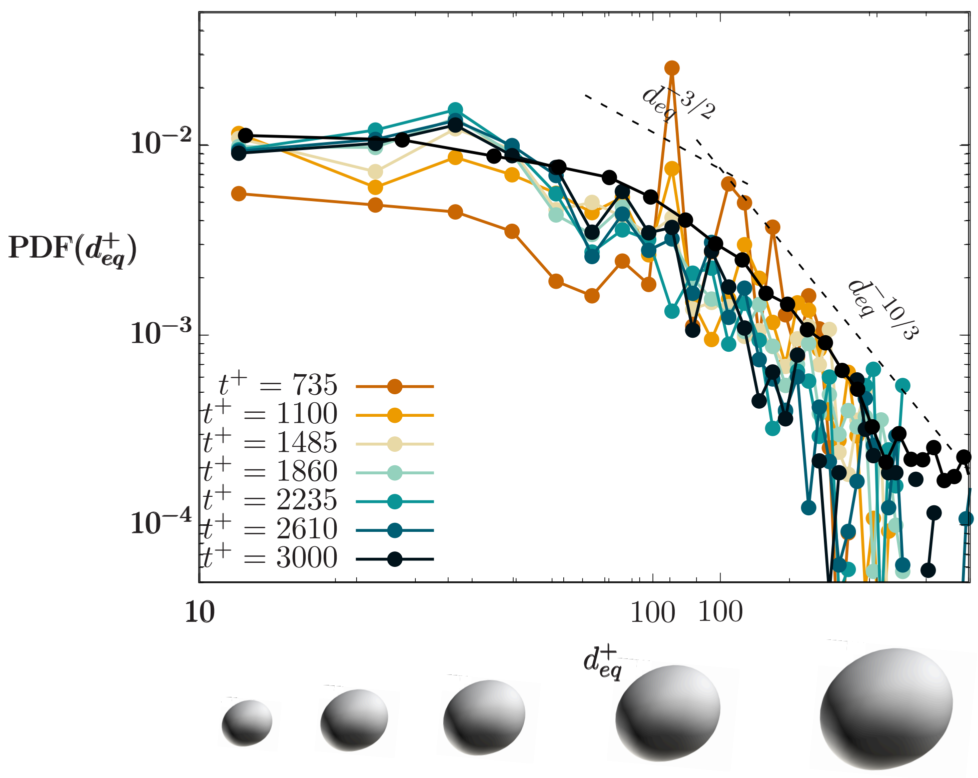
$Pr = 2$

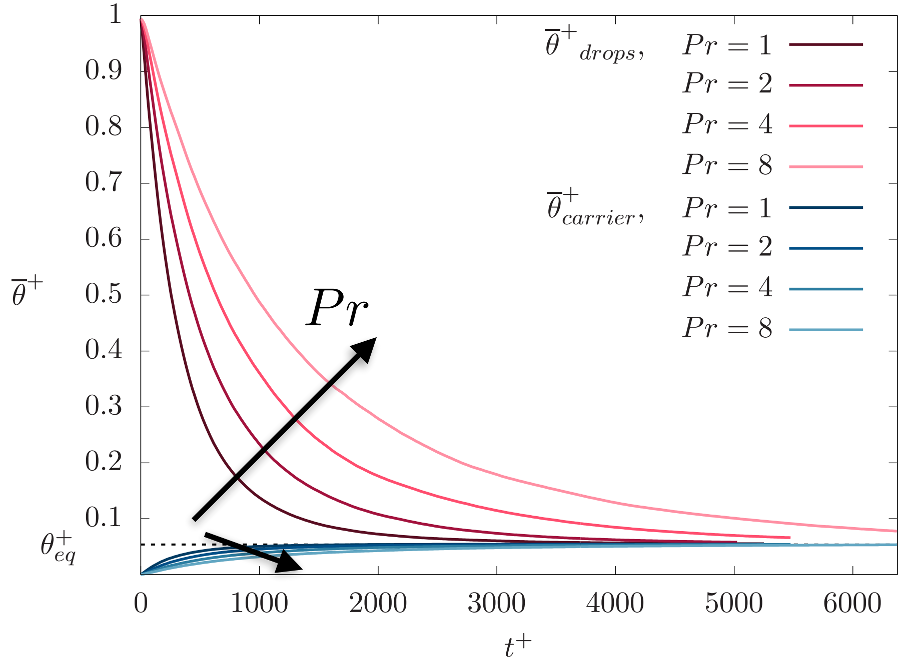
Effect of Prandtl



DSD and average temperature

$$Pr = \frac{\nu}{\alpha}$$





$$\theta_{eq}^+ = \theta_{c,0}^+(1-\Phi) + \theta_{d,0}^+\Phi$$

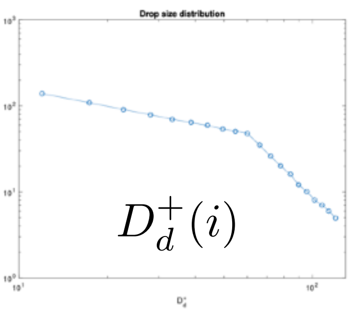
Physical modelling

$$m_d c_p \frac{\partial \theta_d}{\partial t} = \mathcal{H} A_d \left(\theta_f - \theta_d\right)$$

$$\mathcal{H} \sim \lambda_f / \delta_t$$

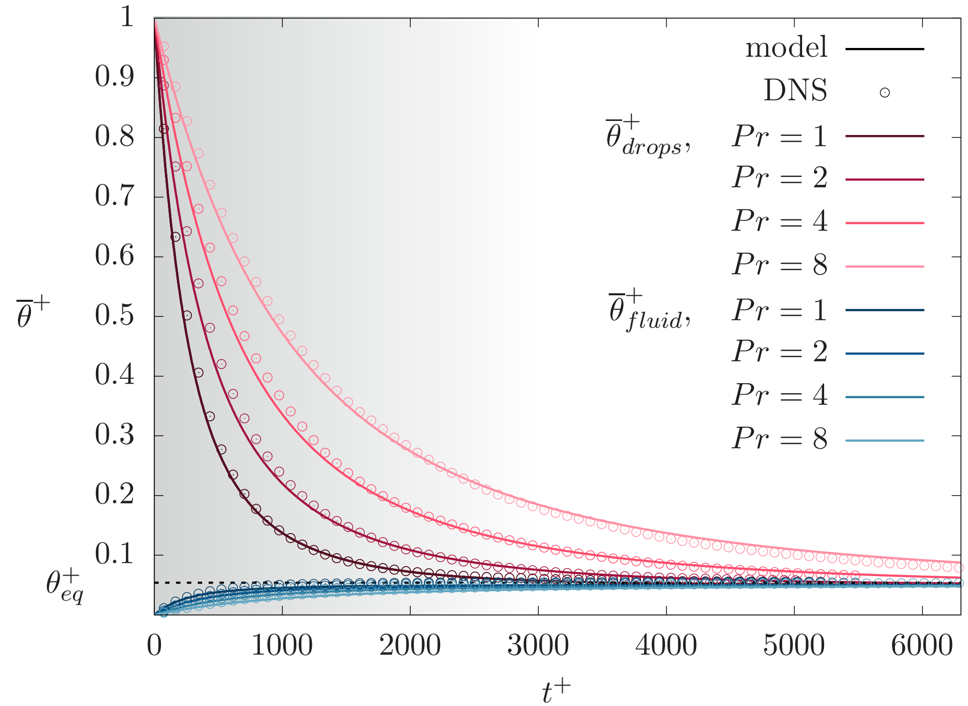
$$\delta_t = \delta Pr^{-1/3}$$

$$\frac{\partial \theta_d^+}{\partial t^+} = \mathcal{C} Pr^{-2/3} \left(D_d^+\right)^{-1} \left(\theta_f^+ - \theta_d^+\right)$$



$$\theta_d^{n+1} = \theta_d^n + \Delta t^+ \mathcal{F}^n$$

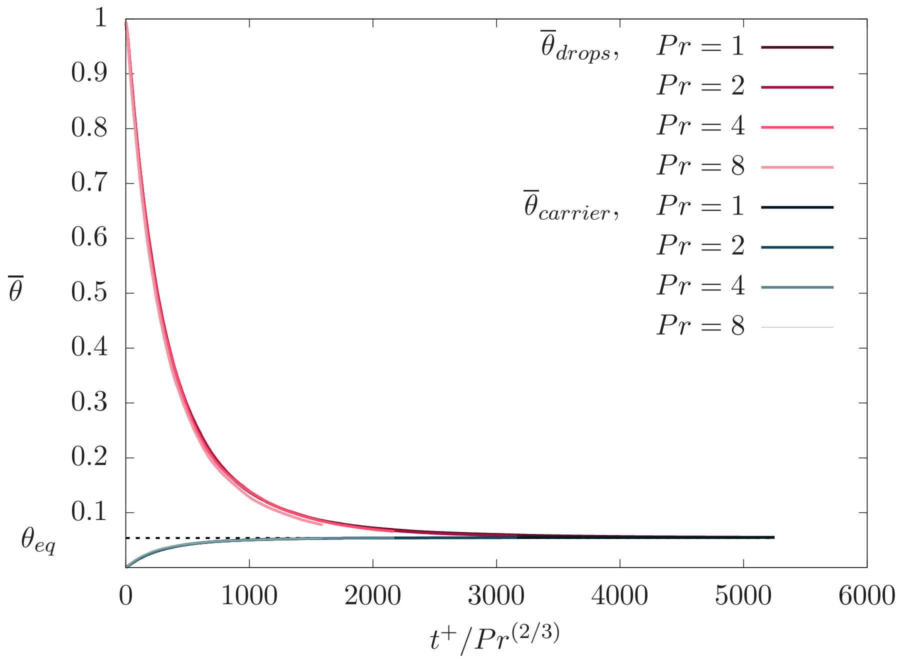
$$\theta_f^{n+1} = \theta_f^n + \Delta t^+ \frac{Q_{tot}}{m_f c_{p,f}}$$



Hp:

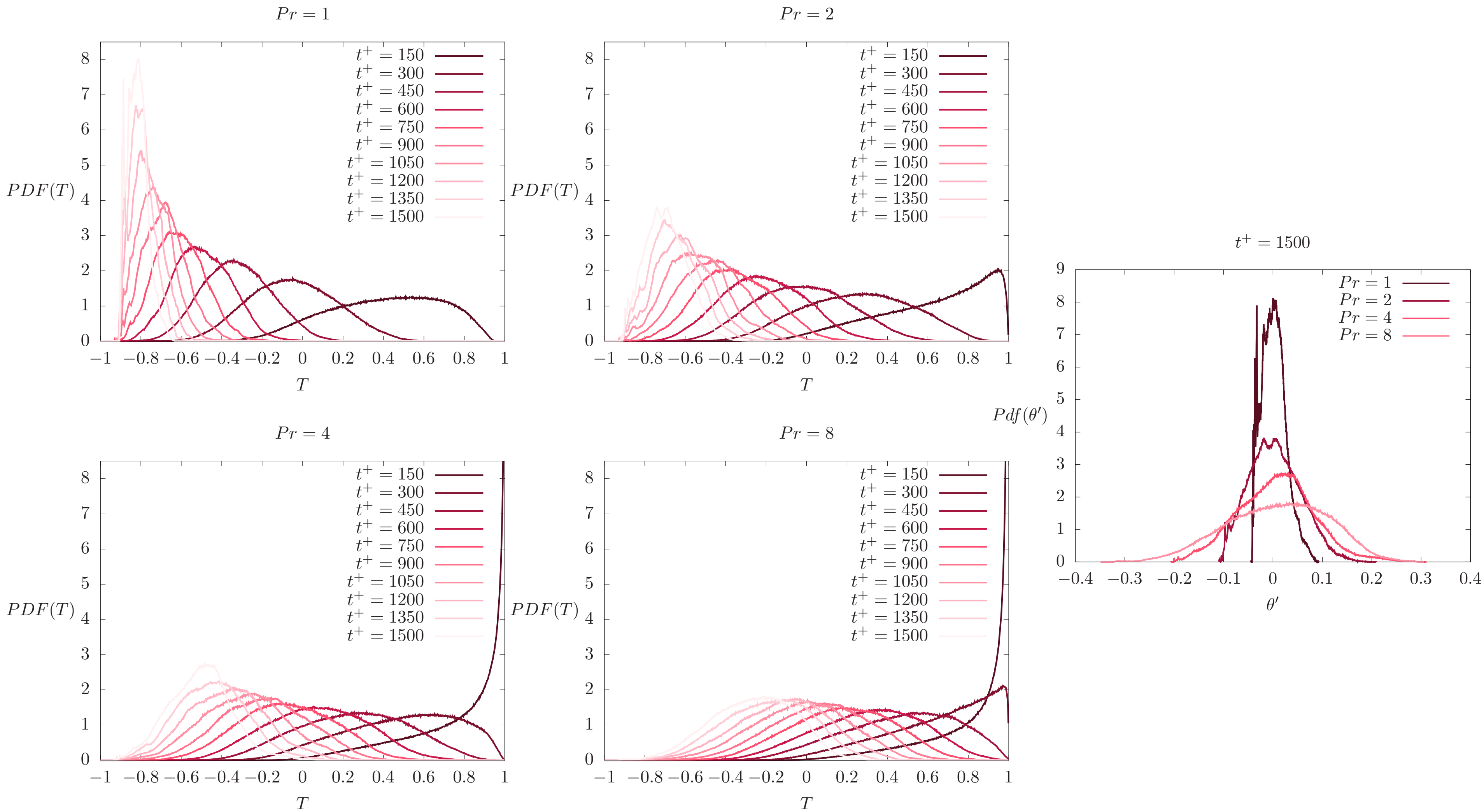
- DSD constant in time
- spherical drops

Scaling law

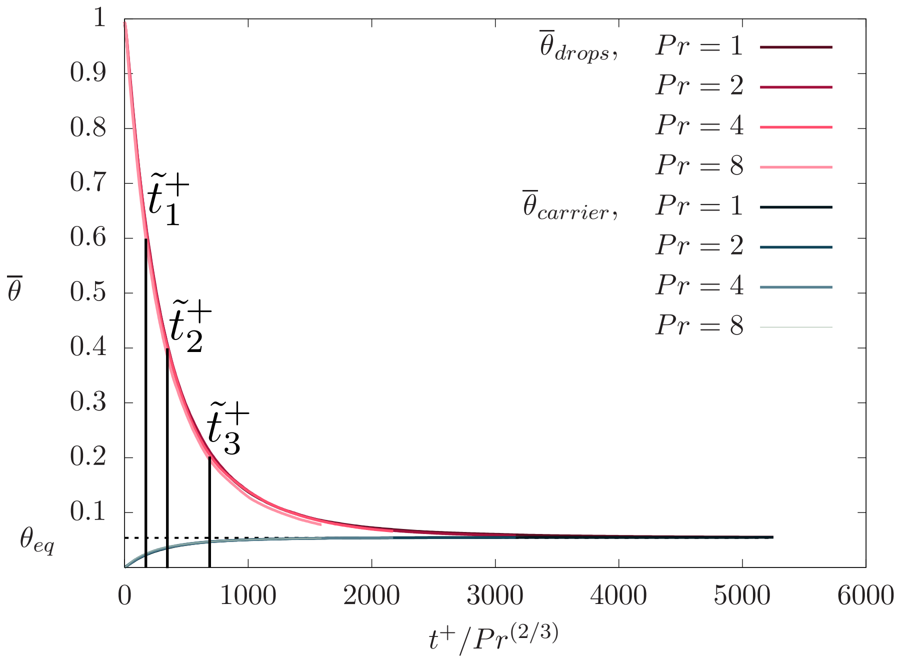


$$\tilde{t}^+ = \frac{t^+}{Pr^{2/3}}$$

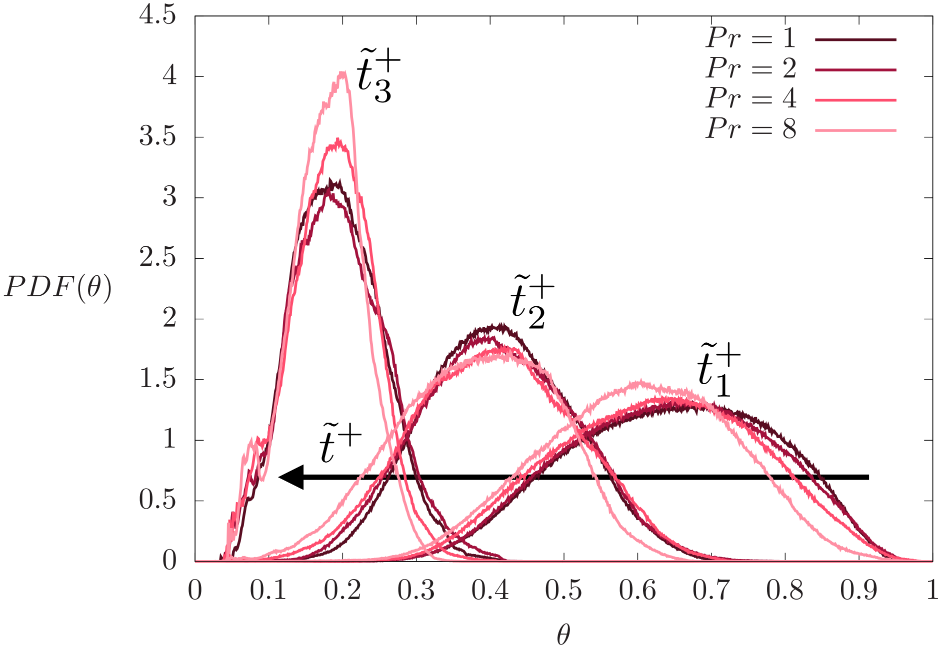
Temperature distribution



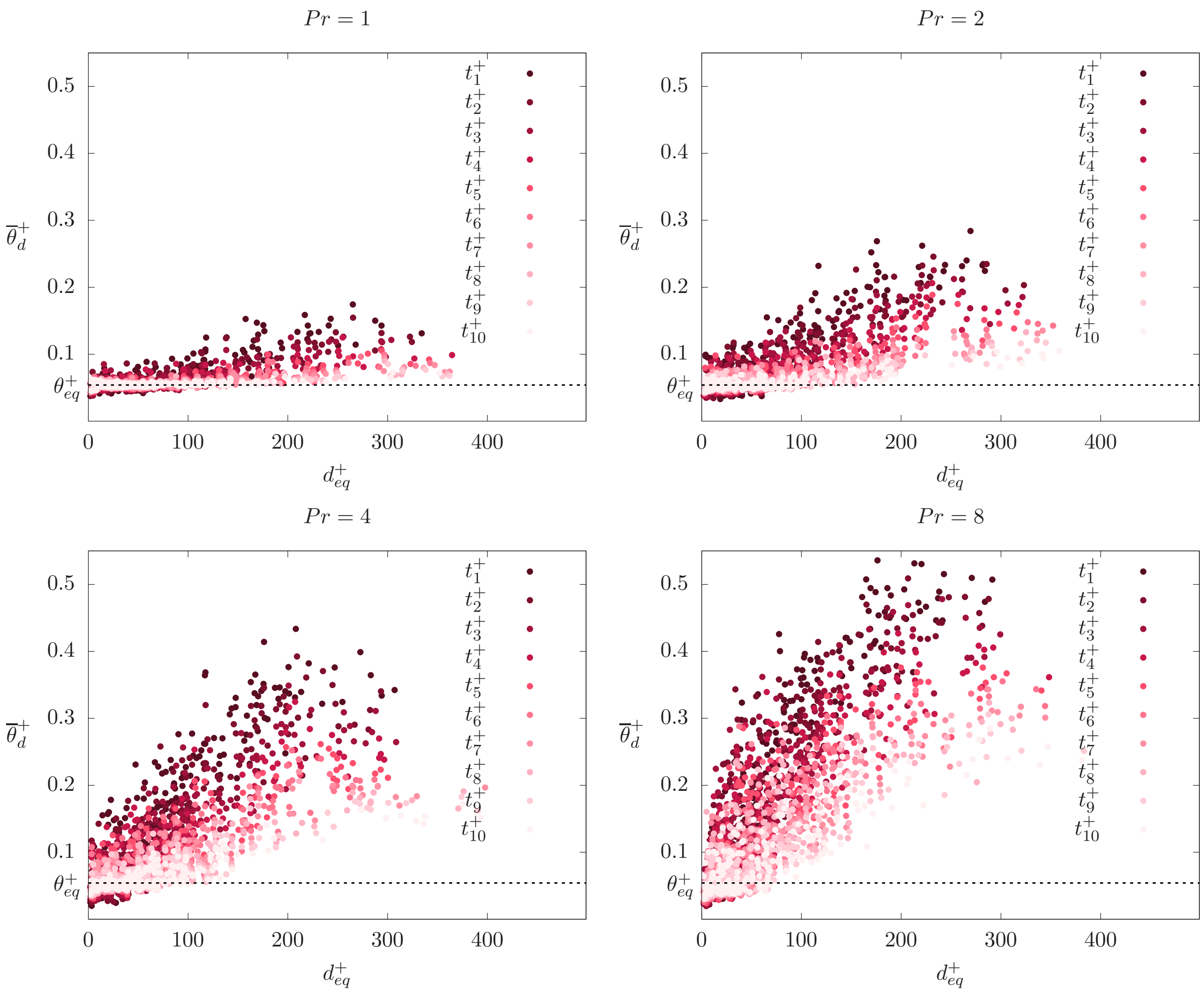
Scaling law



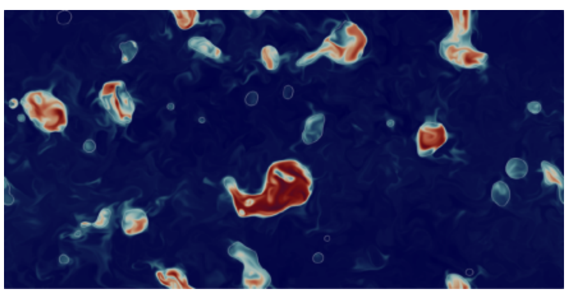
$$\tilde{t}^+ = \frac{t^+}{Pr^{2/3}}$$



Correlation between diameters and temperature

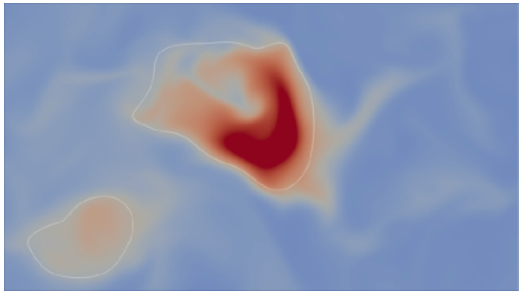


$t_1^+ = 1050$
$t_2^+ = 1200$
$t_3^+ = 1350$
$t_4^+ = 1500$
$t_5^+ = 1650$
$t_6^+ = 1800$
$t_7^+ = 1950$
$t_8^+ = 2100$
$t_9^+ = 2250$
$t_{10}^+ = 2400$



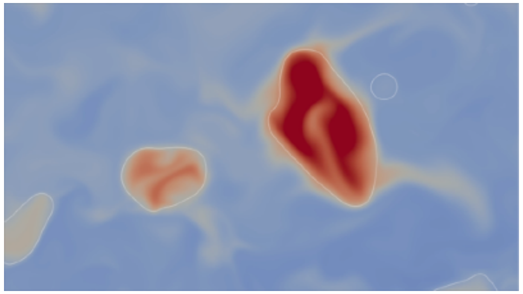
Conclusions

- The heat transfer from the drops to the carrier fluid shows an expected dependency on ***Prandtl:*** the higher is the Pr, the slower is the diffusion and thus the heat transfer between the phases
- We developed an analytical model which can well predict the average temperature of the two phases
- We found a scaling for the time (diffusive time)
- We found a correlation between the diameter and the average temperature



Future developments: local statistics

- Is the drop ***interface area*** correlated with the amount of heat exchanged?
- Do ***Breakages*** and ***Coalescences*** increase or decrease the heat exchange?



Thank you for your attention