Dynamics of large coalescing and breaking droplets in wall bounded turbulence

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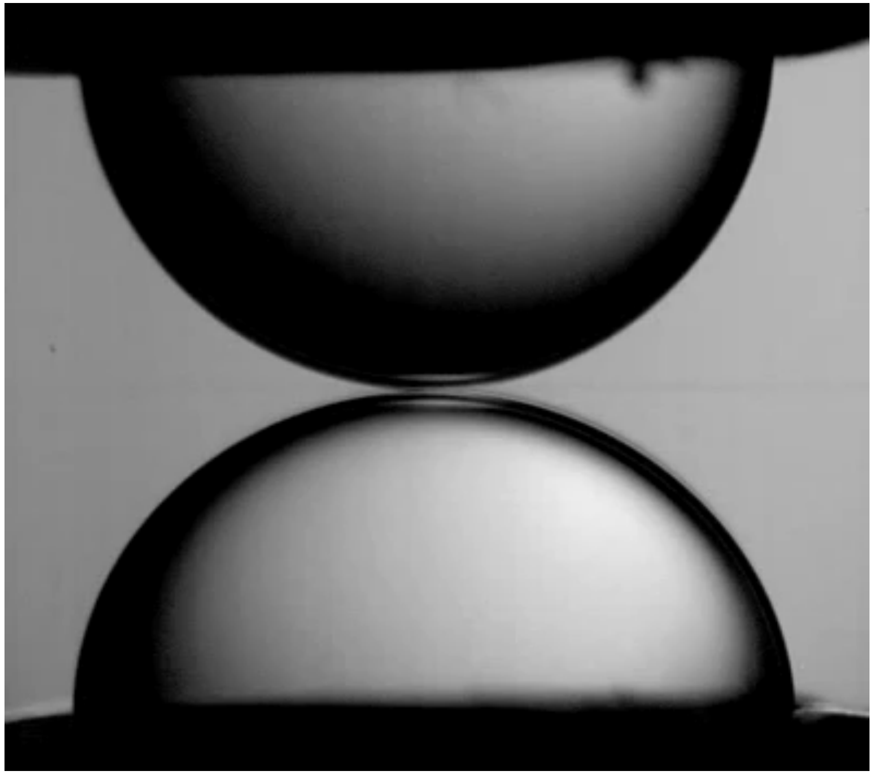
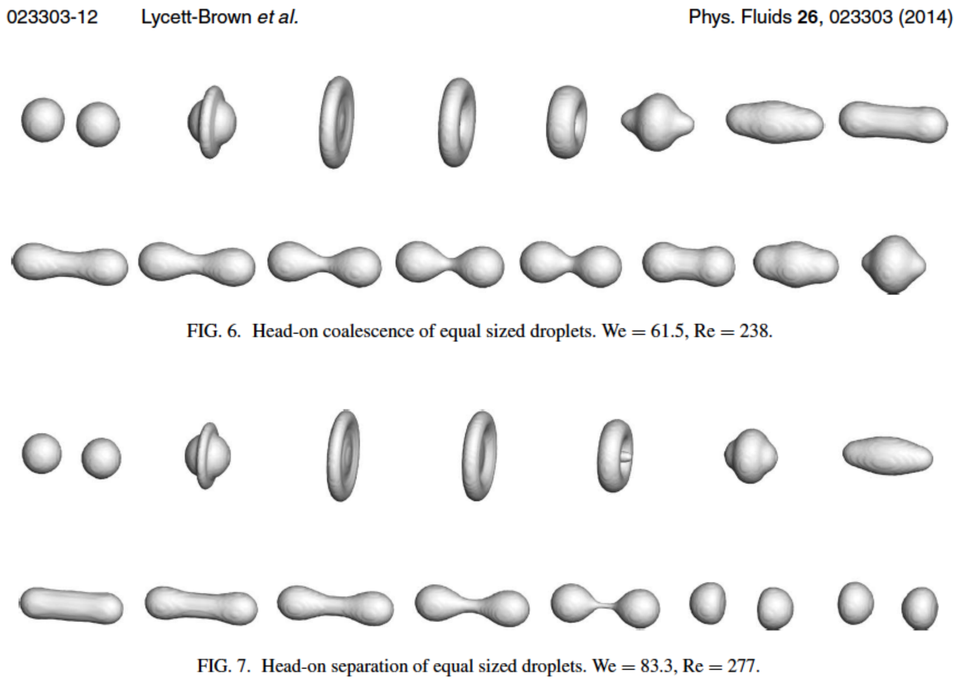
Presentation Outline



Courtesy of
Nicole Sharp, FYFD.

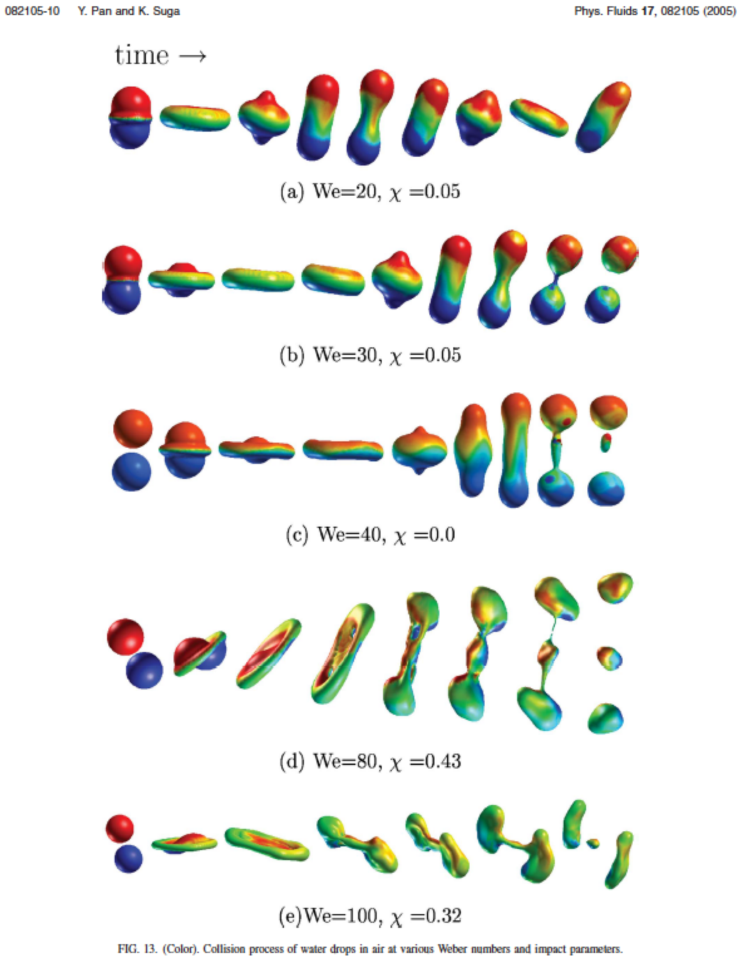
Previous works: Mostly controlled Collisions



023303-12 Lycett-Brown *et al.* Phys. Fluids **26**, 023303 (2014)

FIG. 6. Head-on coalescence of equal sized droplets. We = 61.5, Re = 238.

FIG. 7. Head-on separation of equal sized droplets. We = 83.3, Re = 277.



082105-10 Y. Pan and K. Suga Phys. Fluids **17**, 082105 (2005)

(a) We=20, χ =0.05

(b) We=30, χ =0.05

(c) We=40, χ =0.0

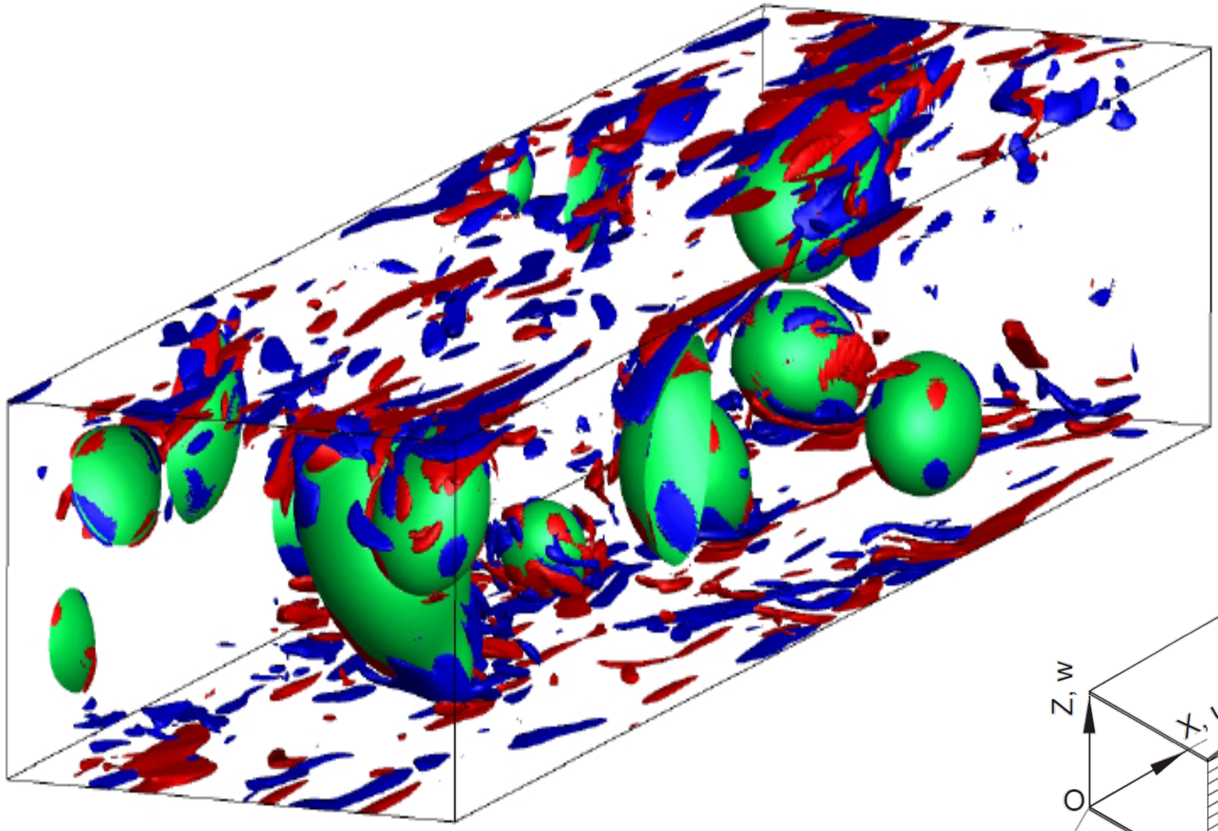
(d) We=80, χ =0.43

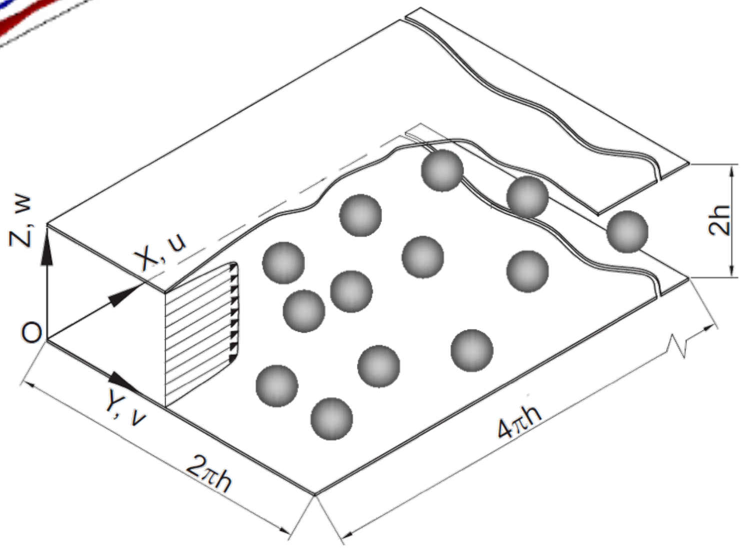
(e)We=100, χ =0.32

FIG. 13. (Color). Collision process of water drops in air at various Weber numbers and impact parameters.

Ashgriz and J. Y. Poo, “Coalescence and separation in binary collisions of liquid drops,” J. Fluid Mech. 221, 183 1990.
Qian and C. K. Law, “Regions of coalescence and separation in droplet collision,” J. Fluid Mech. 331, 59 1997.

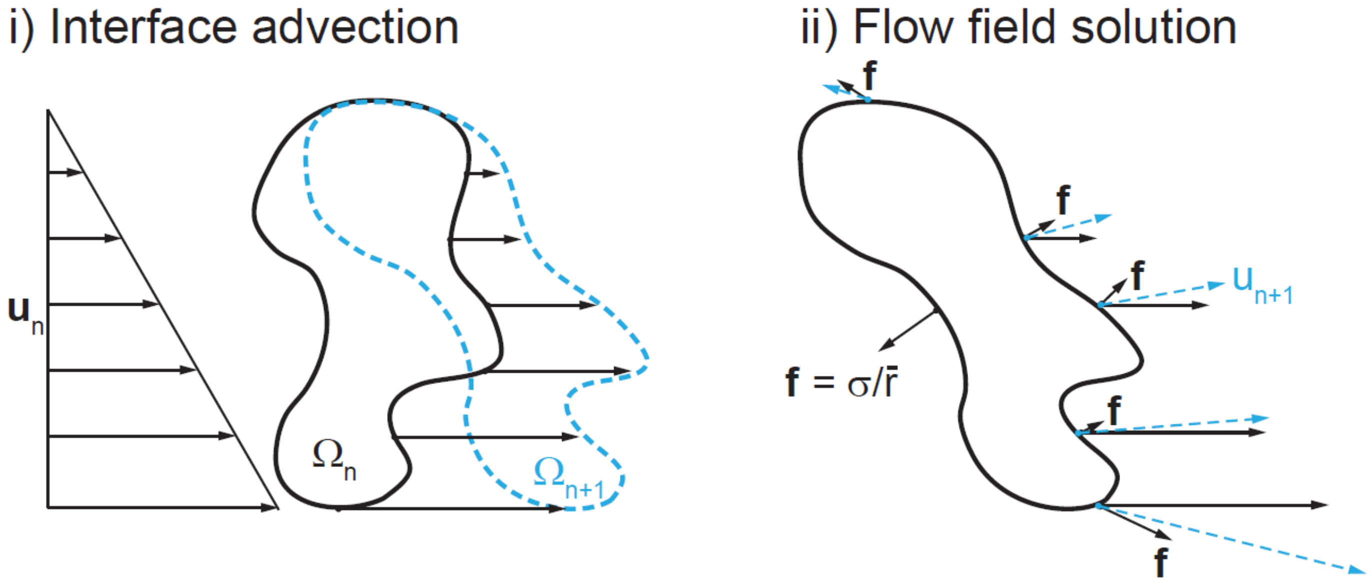
Swarm of large droplets in turbulence



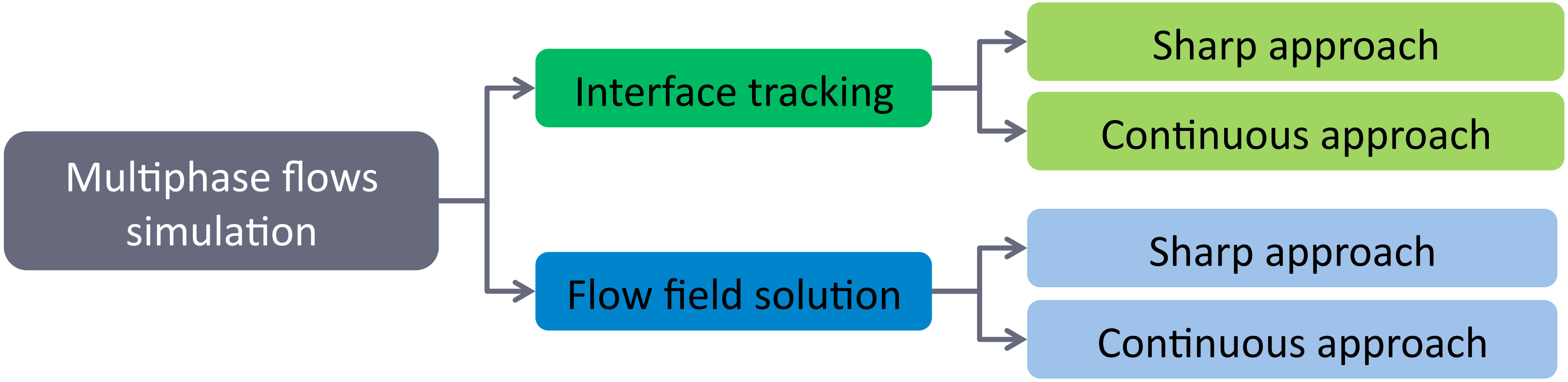


Issues on droplet size distribution, influence on flow field etc…

Multiphase modelling


i) Interface advection

ii) Flow field solution

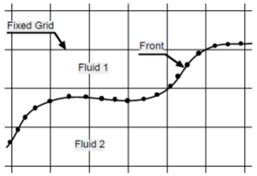

Multiphase flows simulation

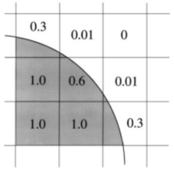
- Interface tracking
  - Sharp approach
  - Continuous approach
- Flow field solution
  - Sharp approach
  - Continuous approach

Multiphase modelling

Interface tracking approaches

- Interface Tracking
  - Sharp approach
    - Front – Capturing
      Tryggvason *et al.*, JCP (2001)
    - Volume Of Fluid (VOF)
      Scardovelli & Zaleski,
      Ann. Rew. Fluid Mec. (1999)
  - Continuous approach
    - Level - Set
      Sussmann *et al.*, JCP (2001)
    - Phase Field Model – Cahn Hilliard



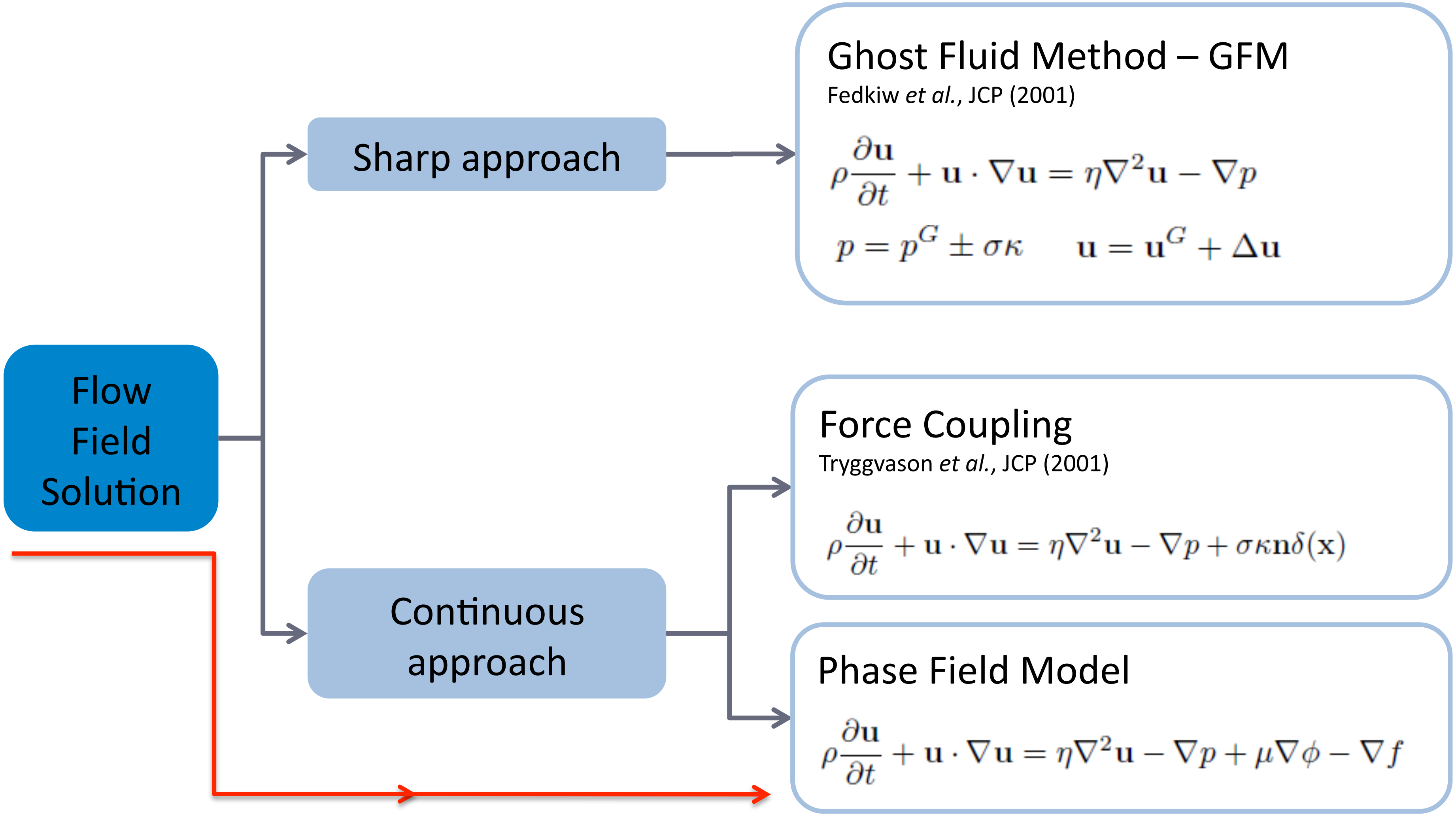


Level - Set:

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = 0$$

Phase Field Model – Cahn Hilliard:

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = \nabla \cdot (M(\phi) \nabla \mu)$$



Flow Field Solution

Sharp approach

Continuous approach

Ghost Fluid Method – GFM

Fedkiw *et al.*, JCP (2001)

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\mathbf{u}\cdot\nabla\mathbf{u}=\eta\nabla^2\mathbf{u}-\nabla p$$

$$p=p^G\pm\sigma\kappa \qquad \mathbf{u}=\mathbf{u}^G+\Delta\mathbf{u}$$

Force Coupling

Tryggvason *et al.*, JCP (2001)

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\mathbf{u}\cdot\nabla\mathbf{u}=\eta\nabla^2\mathbf{u}-\nabla p+\sigma\kappa\mathbf{n}\delta(\mathbf{x})$$

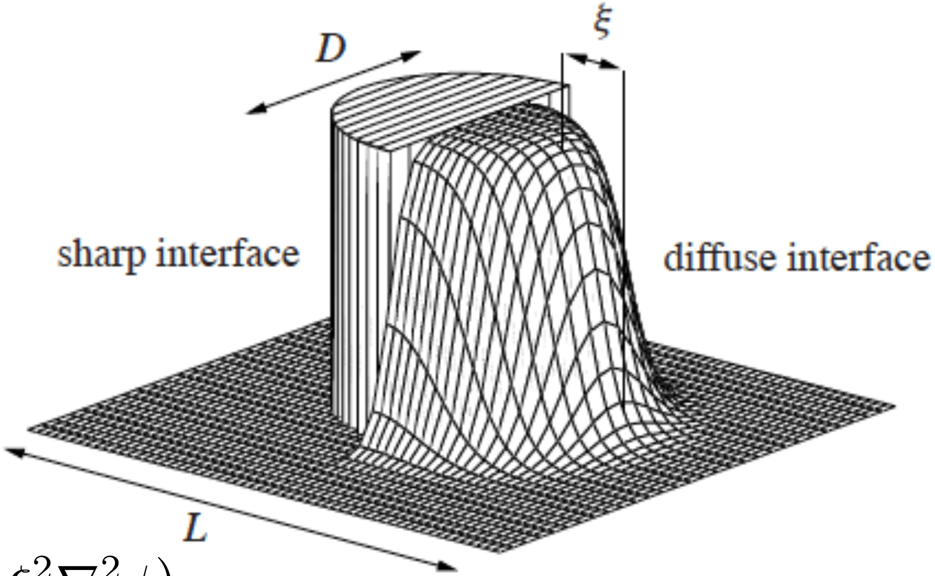
Phase Field Model

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\mathbf{u}\cdot\nabla\mathbf{u}=\eta\nabla^2\mathbf{u}-\nabla p+\mu\nabla\phi-\nabla f$$

Interface tracking

Summary of Phase Field Model

$$-1 \leq \phi \leq 1$$



Cahn – Hilliard equation

$$\frac{\partial \phi}{\partial t} = \overbrace{-(\mathbf{u} \cdot \nabla)\phi}^{\text{TRANSPORT}} + \underbrace{\nabla \cdot (M \nabla \mu)}_{\text{CONFINED MIXING}}$$

Chemical Potential $\mu = \frac{\delta F}{\delta \phi} = \frac{3\sigma}{2\sqrt{2}\xi}\left(\phi^3 - \phi - \xi^2 \nabla^2 \phi\right)$

Surface Tension $= \sigma$

→ Interface Thickness $= \xi \ll H$

Mobility $= M$

Dimensionless numbers

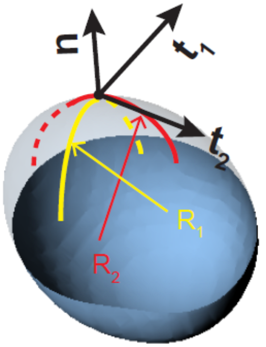
→ $Ch = \frac{\xi}{H} \quad Pe = \frac{M\sigma}{\xi U_\tau H}$

Simulations

Single Phase(Navier – Stokes) + Force coupling

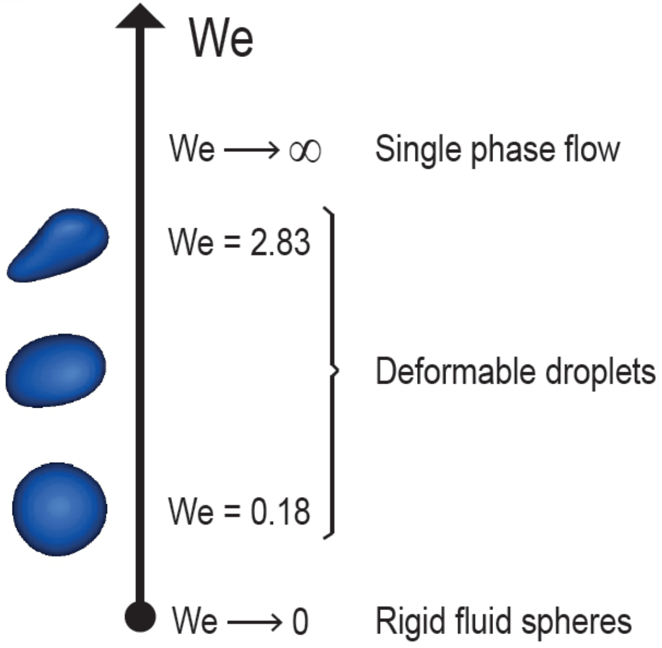
$$\frac{\partial \mathbf{u}}{\partial t} = -(\mathbf{u}\cdot\nabla)\mathbf{u} + \frac{1}{Re_\tau}\nabla^2\mathbf{u} - \nabla p + \underbrace{\frac{\mu}{We\,Ch}\nabla\phi}_{f_c}$$

$$\nabla\cdot\mathbf{u} = 0$$



Dimensionless numbers

$$Re = \frac{\rho U_\tau H}{\eta} \qquad Ch = \frac{\xi}{H} \qquad We = \frac{\rho U_\tau^2 H}{\sigma}$$


We

$We \longrightarrow \infty$ Single phase flow

We = 2.83

Deformable droplets

We = 0.18

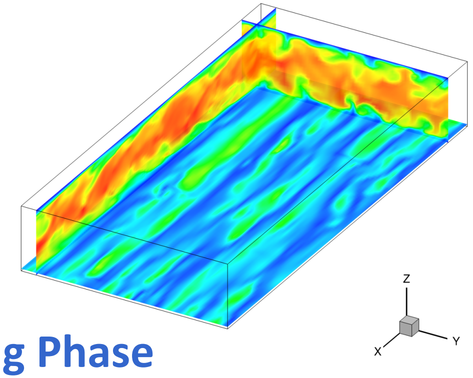
$We \longrightarrow 0$ Rigid fluid spheres

Validation

L. Scarbolo, A. Soldati et. al., Unified framework for a side-by-side comparison of different multicomponent algorithms , *J. Comp. Phys.* 234 (2013)

Test case

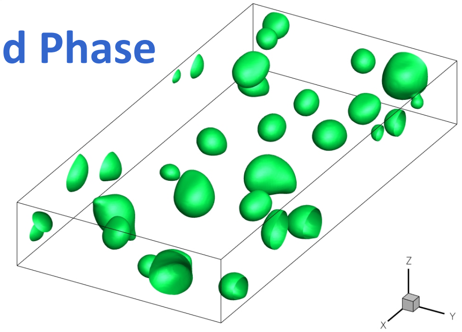
Two phase turbulent flow in a channel like geometry



Carrying Phase

+

Dispersed Phase



Hypotheses

- same density;
- same viscosity;
- variable surface tension;
- complete description of turbulence.

Deformability

Droplet inertia

Turbulence

Benchmark for further analyses

Database

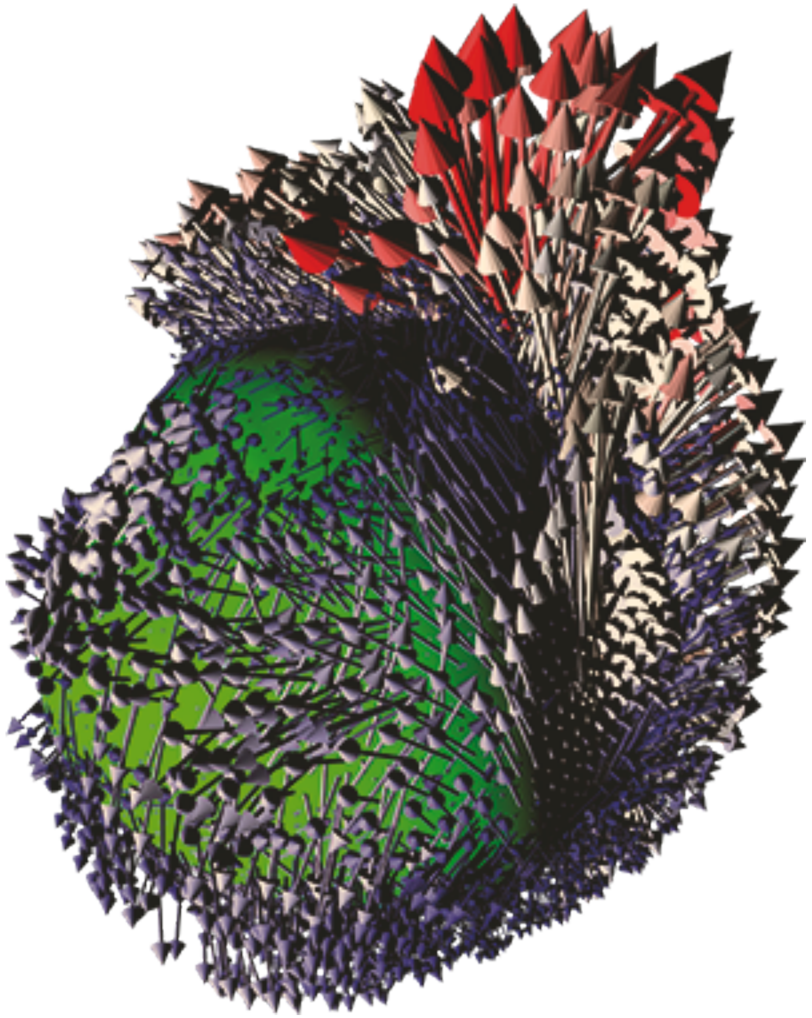
Simulation parameters:

Re_τ	150
We	0.18 ÷ 2.8
d	65 w. u.
Pe	$\propto Ch^{-1}$
Ch	0.0185
N_x x N_y x N_z	512 x 256 x 257
h	150 w.u.
L_x x L_y x L_z	$4\pi h$ x $2\pi h$ x 2h
Volume fraction	5%
l_ξ	7.5 w.u.

$$d >> \eta_k$$

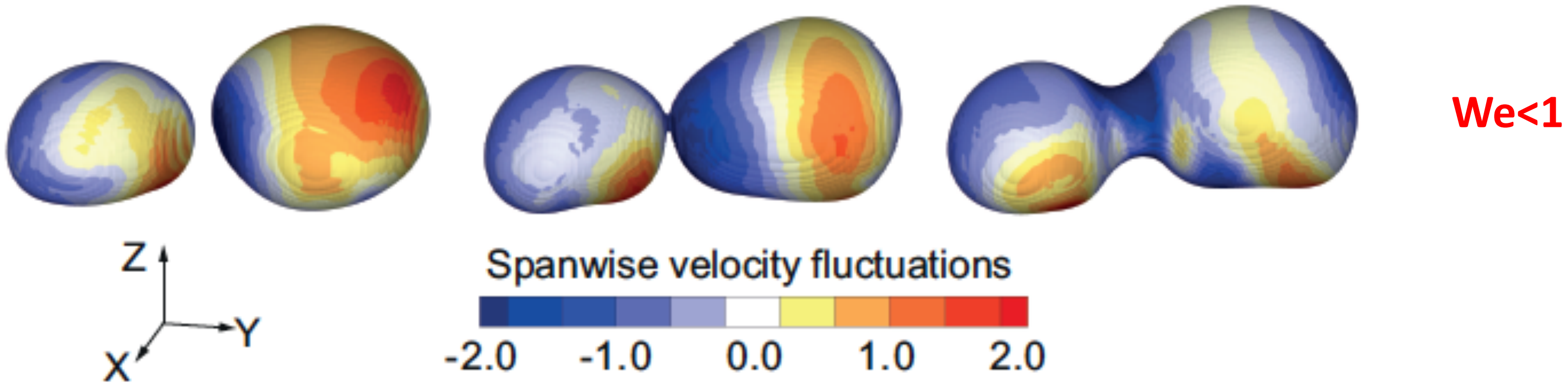
Pseudo Spectral Method:
Fourier Chebychev Series

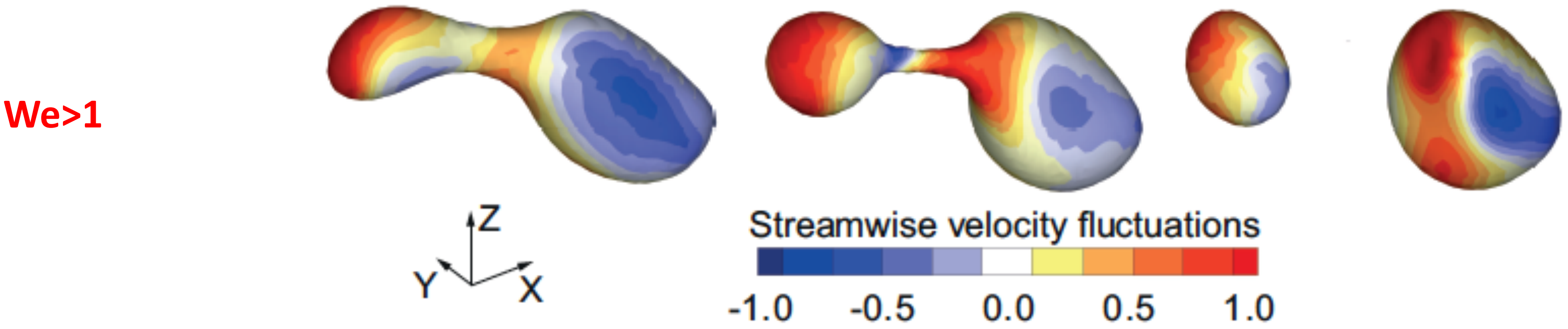
Close up: single deformable (unbreakable) drop



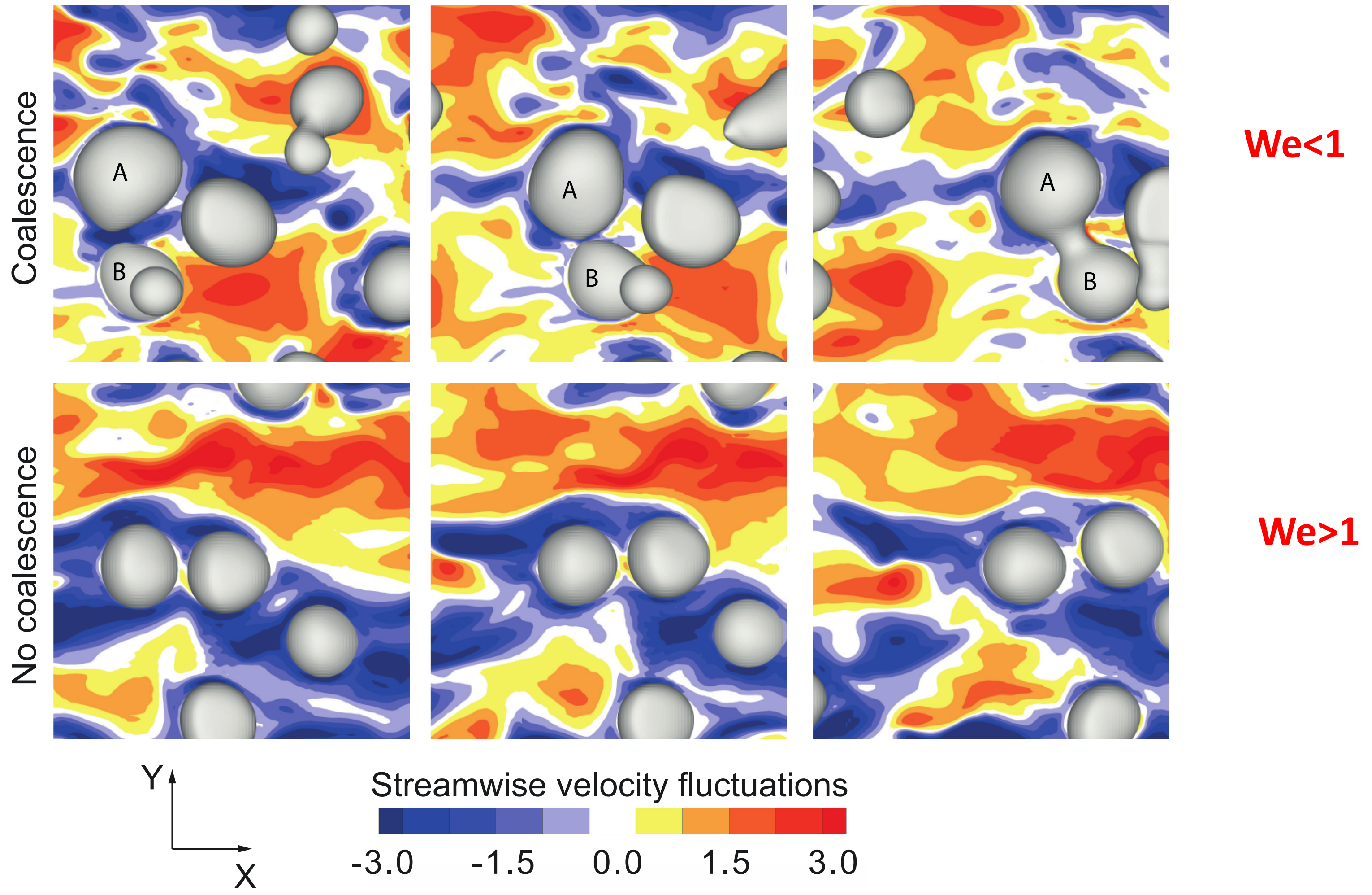
Droplets coalescence/break-up

Weber number controls the dynamic of the coalescence/break-up

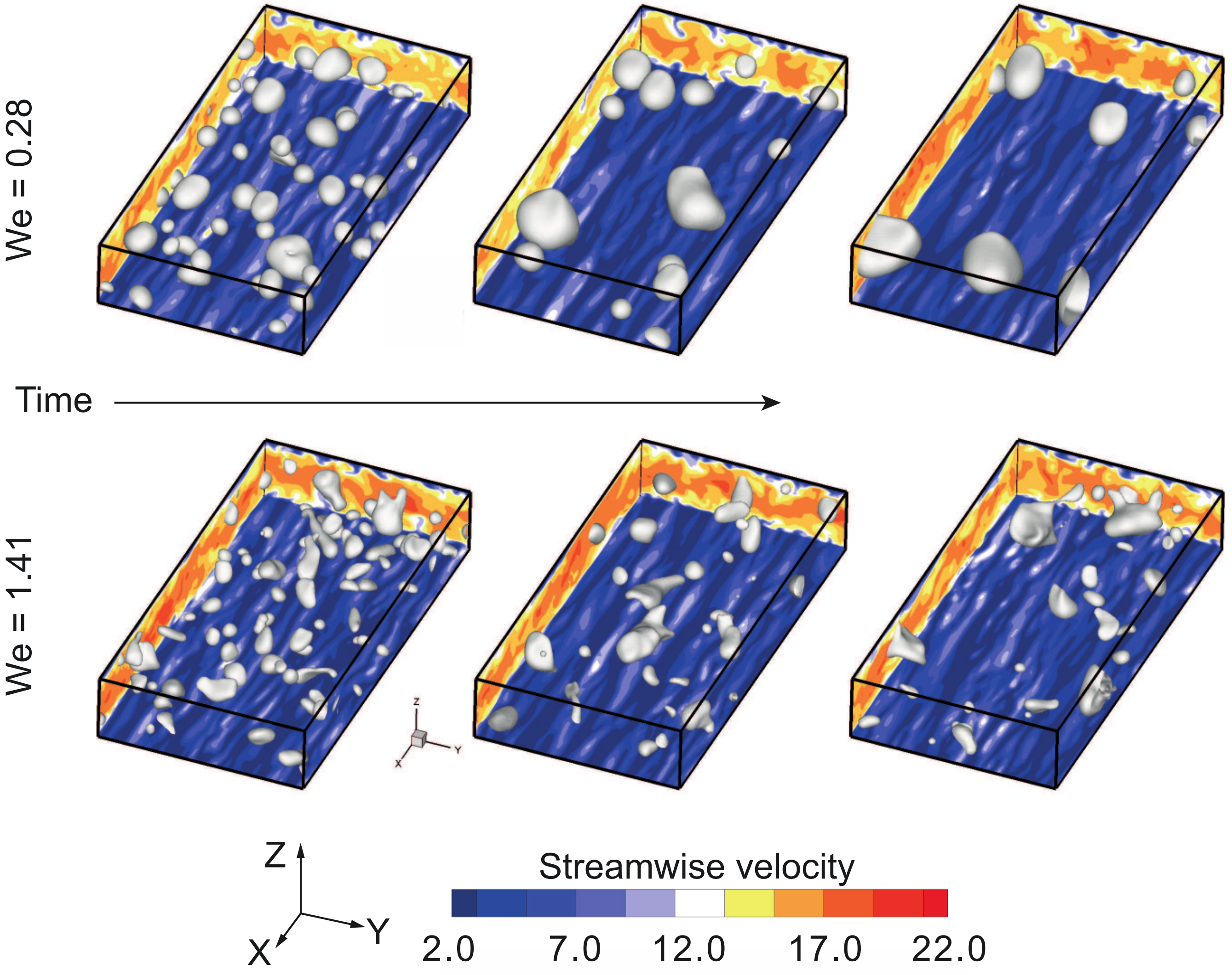




Droplets coalescence/break-up



What happens to drops distribution? It depends on Weber Number

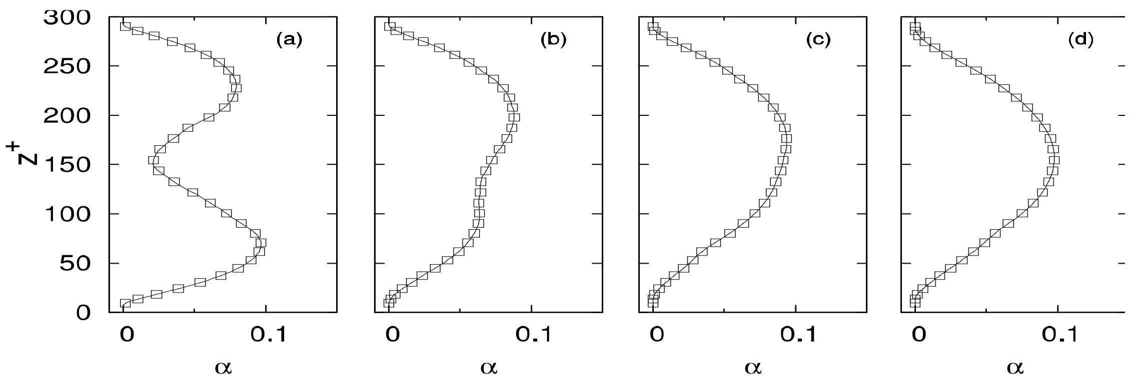


Droplets concentration

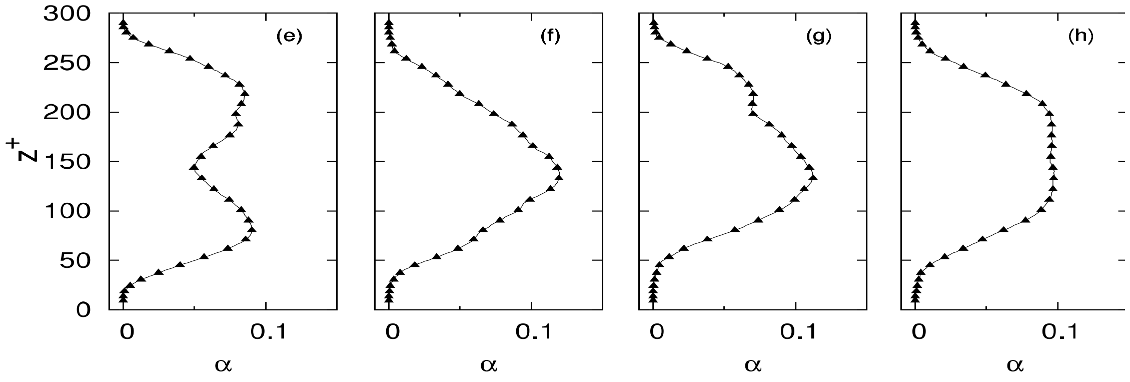
Droplets migrate to the center of the channel

Same behavior for different Weber N.

We=0.025

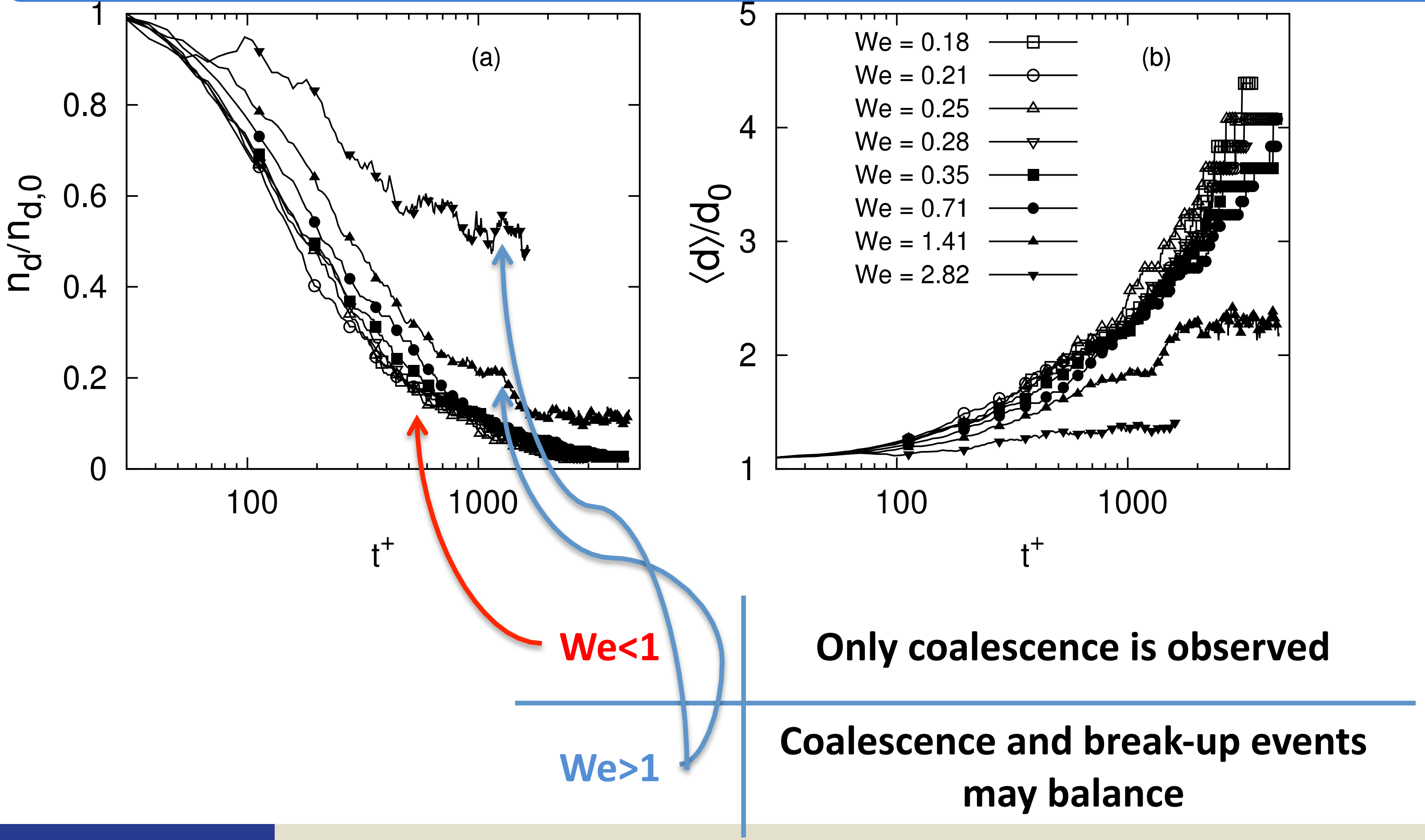


We=1.41



Droplets coalescence/break-up

Number of Drops & Diameter of Drops



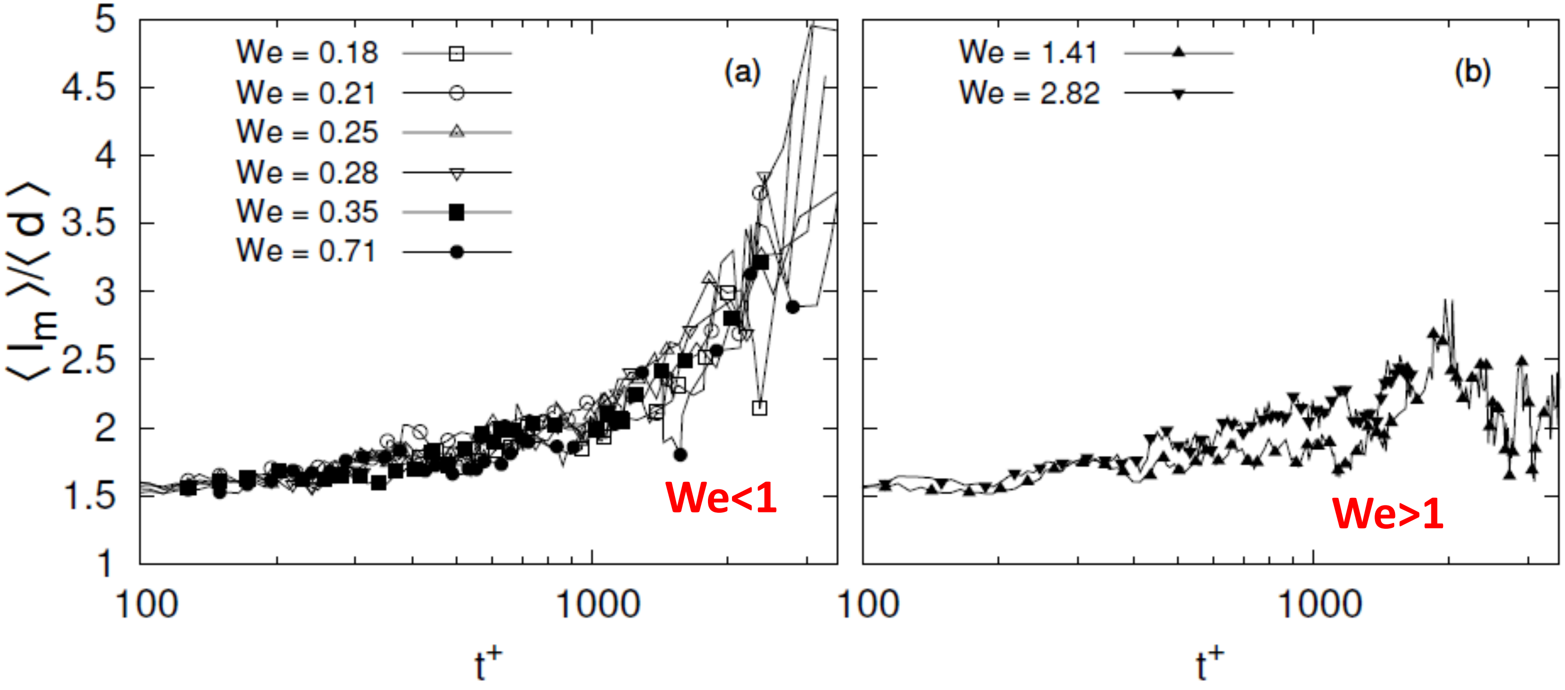
We<1 | **Only coalescence is observed**

We>1 | **Coalescence and break-up events may balance**

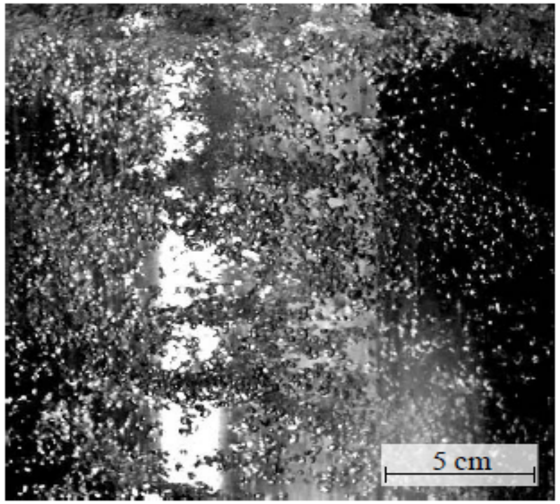
Droplet distance

We<1: Inter-droplet distance prevent coalescence

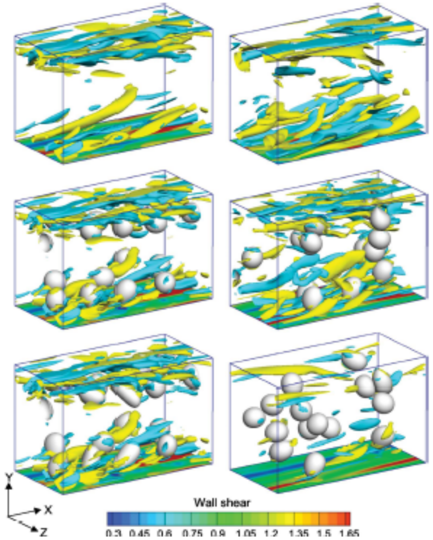
We>1: Inter-droplet upper bounded



Carrier phase dynamics



D.P.M. van Gils, JFM 722 (2013)



J. Lu, POF 17 (2005)

Bubbles in turbulence

- deformability;
- viscosity difference;
- density difference;

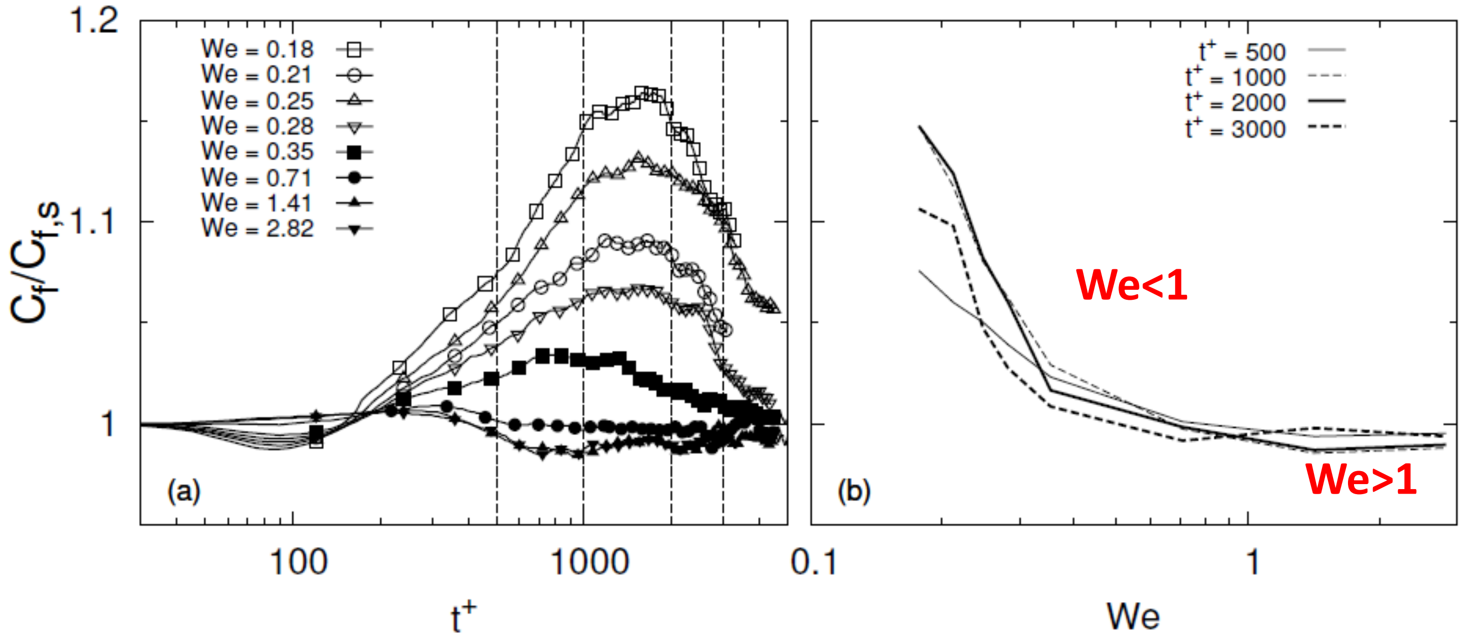
Bubbles in turbulence

- deformability;
- same viscosity;
- density difference.

Wall drag modification

Deformability plays key role

Stream-wise velocity



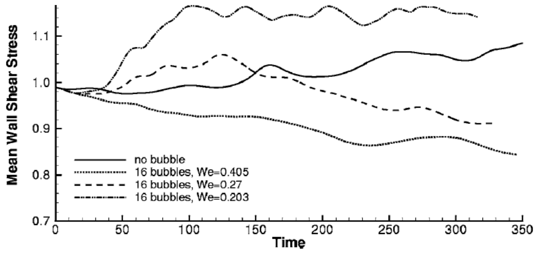
We<1

We>1

$$C_f = \frac{2\tau_w}{\rho u_0^2}$$

Drag dependent on We

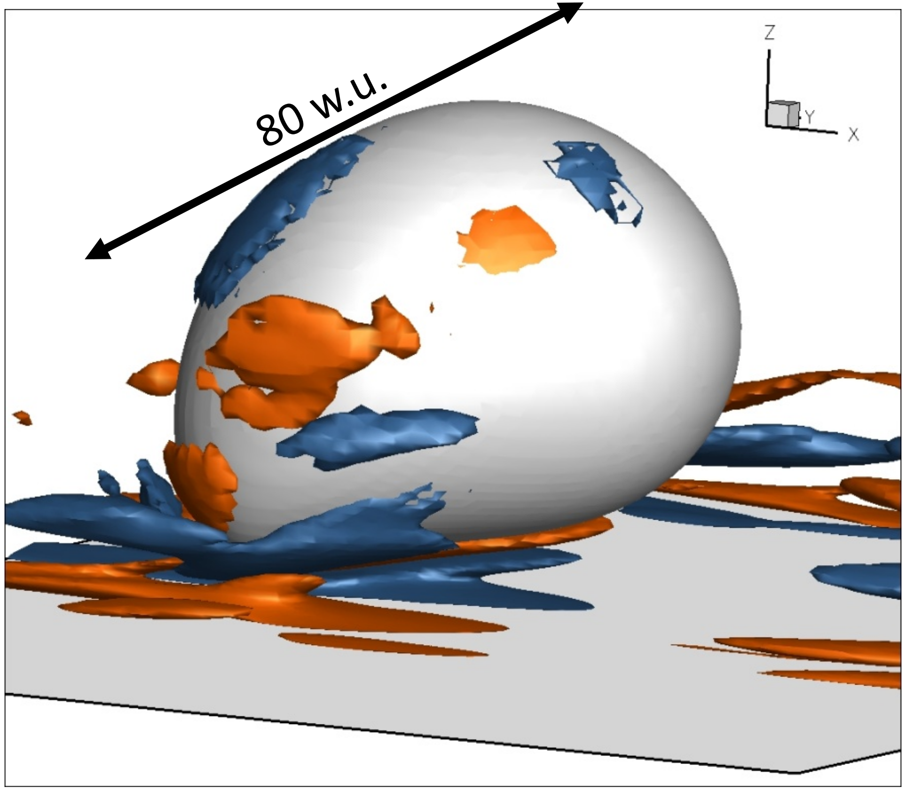
Drag depends on diameter and number of droplets



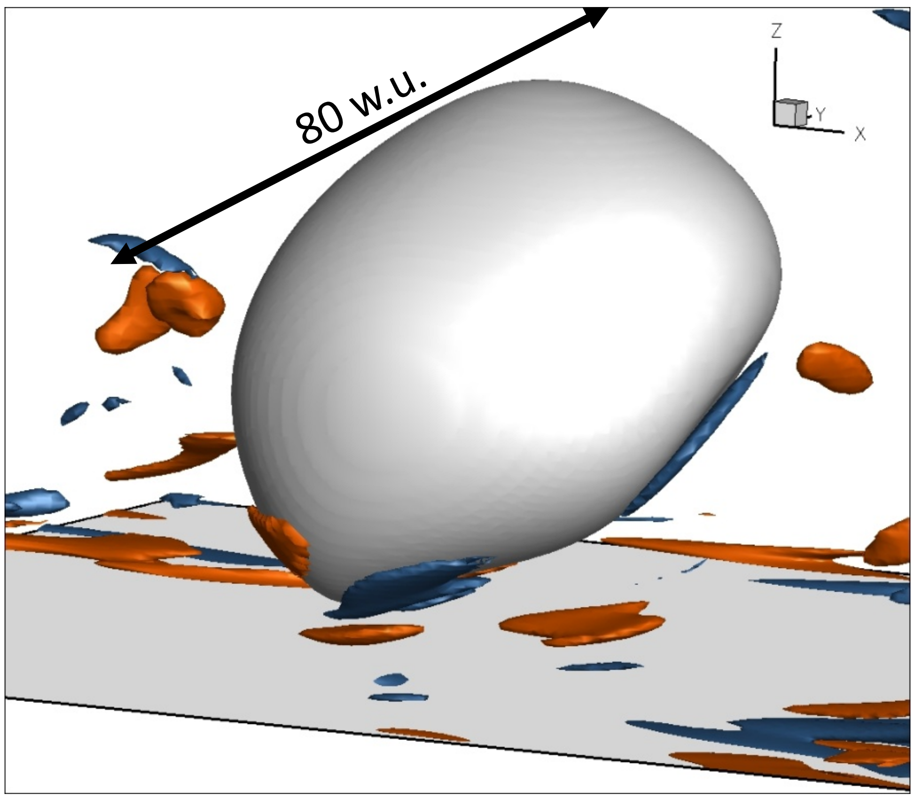
J. Lu, POF 17 (2005)

Near-wall vorticity

We = 0.21 - $C_f/C_{f,S}$ = 1.11

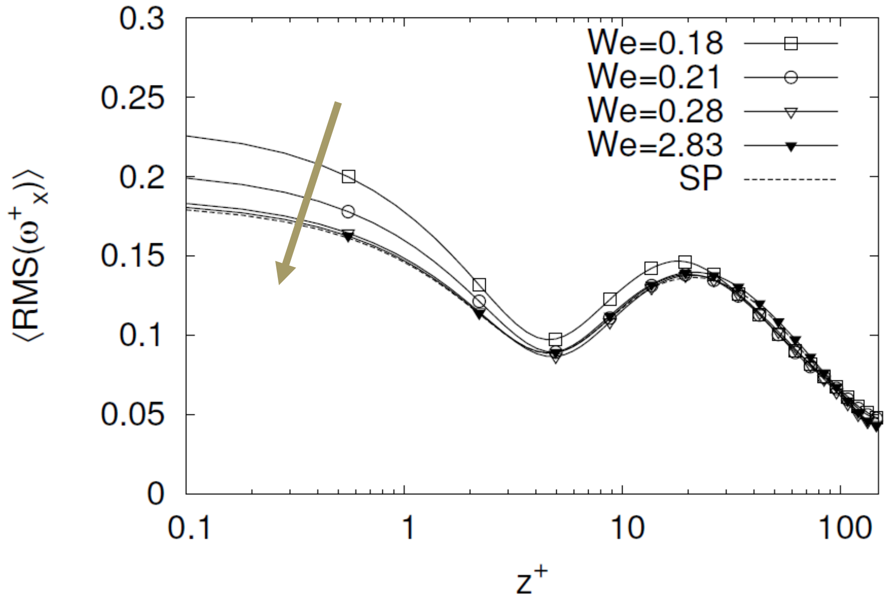


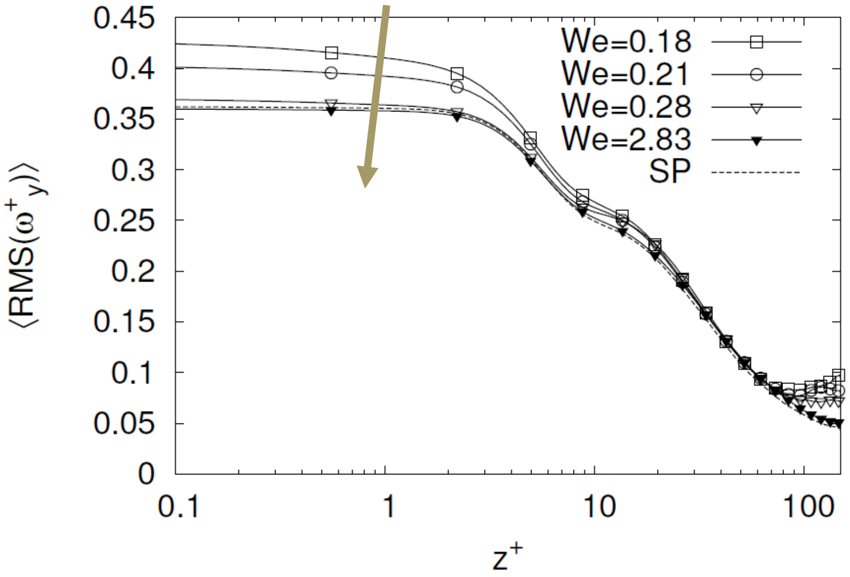
We = 0.35 - $C_f/C_{f,S}$ = 1,00



Streamwise vorticity

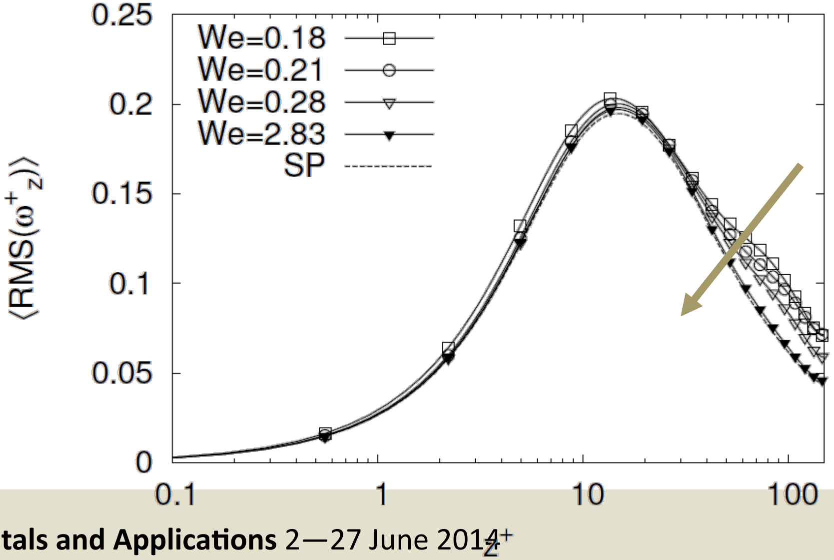
Near-wall vorticity





Transport of high strm-wise momentum near the wall

Transport of low strm-wise momentum towards channel center



Mechanisms

Drag **E**nhancement produced by droplets flow obstruction

High momentum transported in the near the wall region

Low strm-wise momentum to the center of the channel

Drag Enhancement dependent on droplets diameter, number and deformability

External droplets surface diminishes with droplets number

Streamwise velocity gradients increase with the diameter

Effects modulated by defromability

Conclusions

Dispersed phase

- Weber N. controls coalescence/breakup
- Turbulence yield to a critical Weber N.
- Uniform coalescence rate for sub-critical We

Carrier phase

- Turbulent field modified by the presence of droplets
- Friction coefficient is increeased
- Friction is function of diameter and droplets number

Acknowledgements

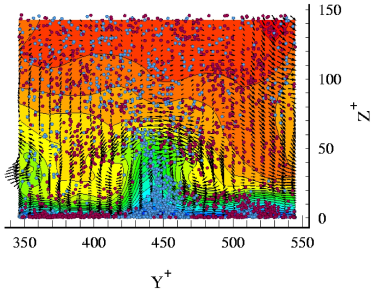
Thank you &

PRACE

CINECA

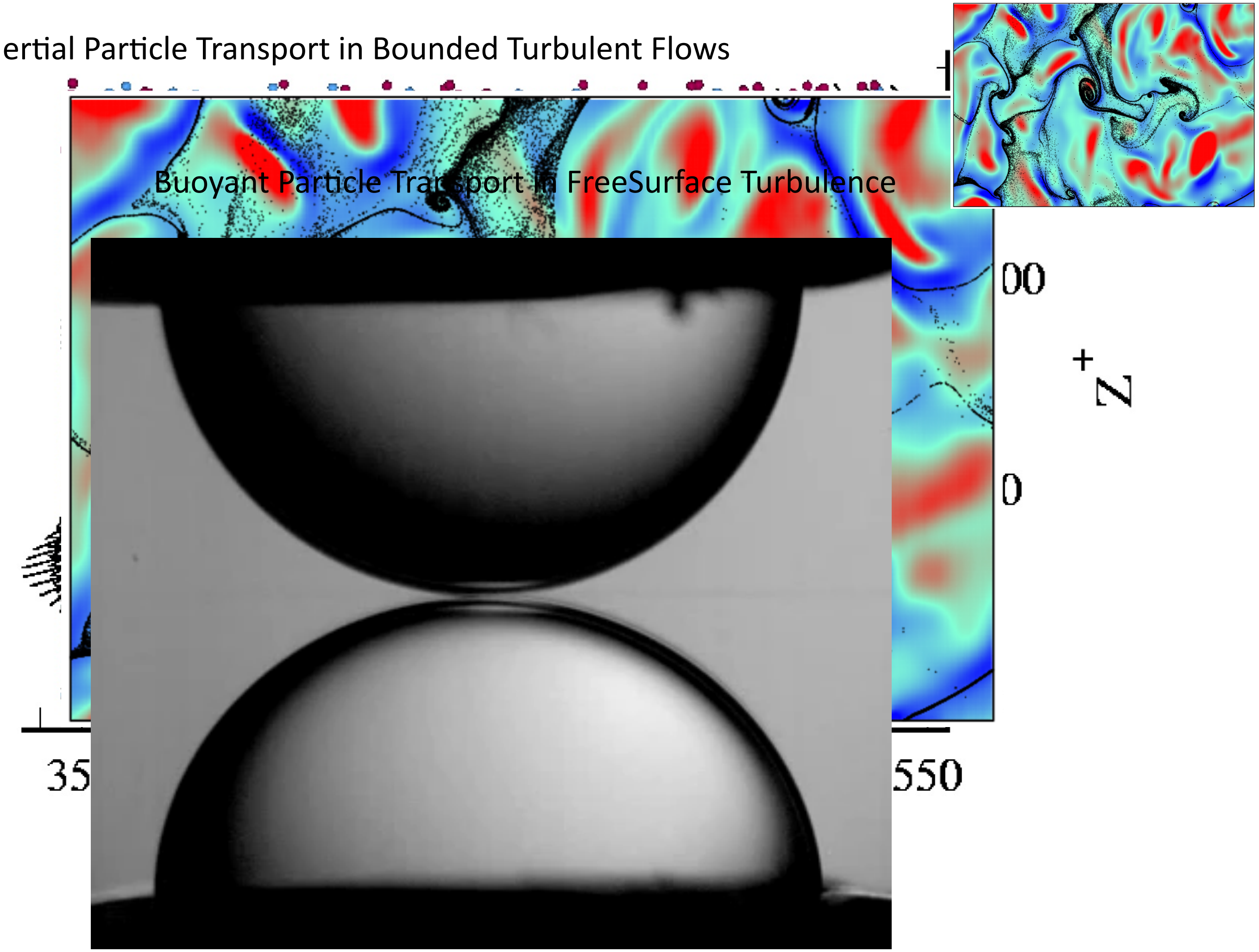
NORDITA
Nordic Institute for Theoretical Physics

Presentation Outline



Inertial Particle Transport in Bounded Turbulent Flows

Buoyant Particle Transport in FreeSurface Turbulence

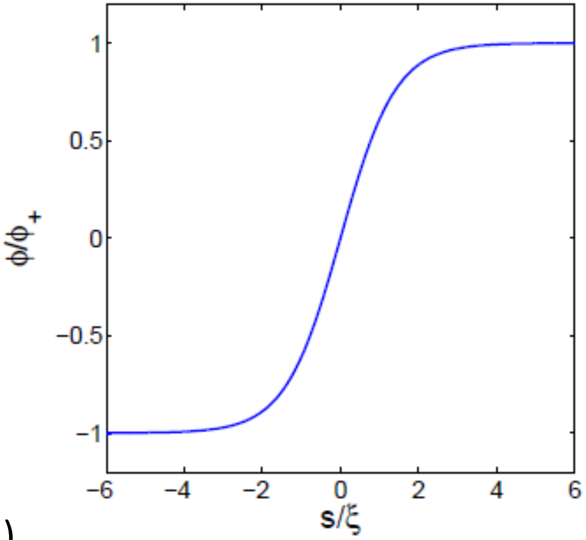


Interface tracking

Phase Field Model

At equilibrium: Interface relaxation

$$\mu = 0 \Longrightarrow \begin{cases} \frac{s}{\xi} >> 1 \rightarrow \phi(s) = \phi_+ \\ \frac{s}{\xi} << -1 \rightarrow \phi(\mathbf{x}) = \phi_- \\ \phi(s) = \phi_+ \tanh\left(\frac{s}{\sqrt{2}\xi}\right) \end{cases}$$

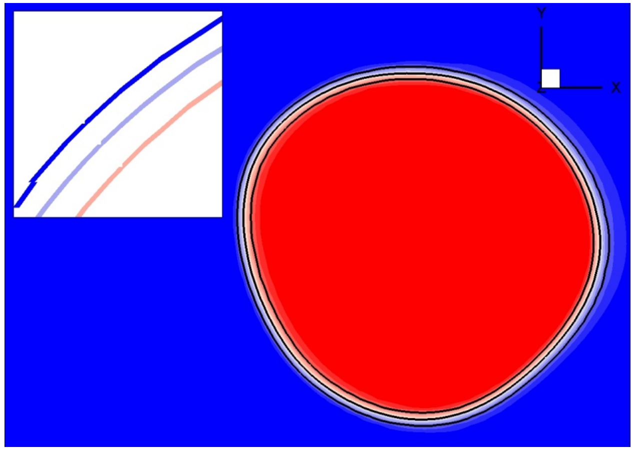


Asymptotic analysis:

Magaletti, Casciola *et al.*, JFM (2013)

- Correct advection of the interface;
- Fast interface relaxation;

$$\begin{cases} Ch \ll 1 \\ Pe^{opt} \approx \dfrac{1}{3Ch} \end{cases}$$



Droplet in turbulence