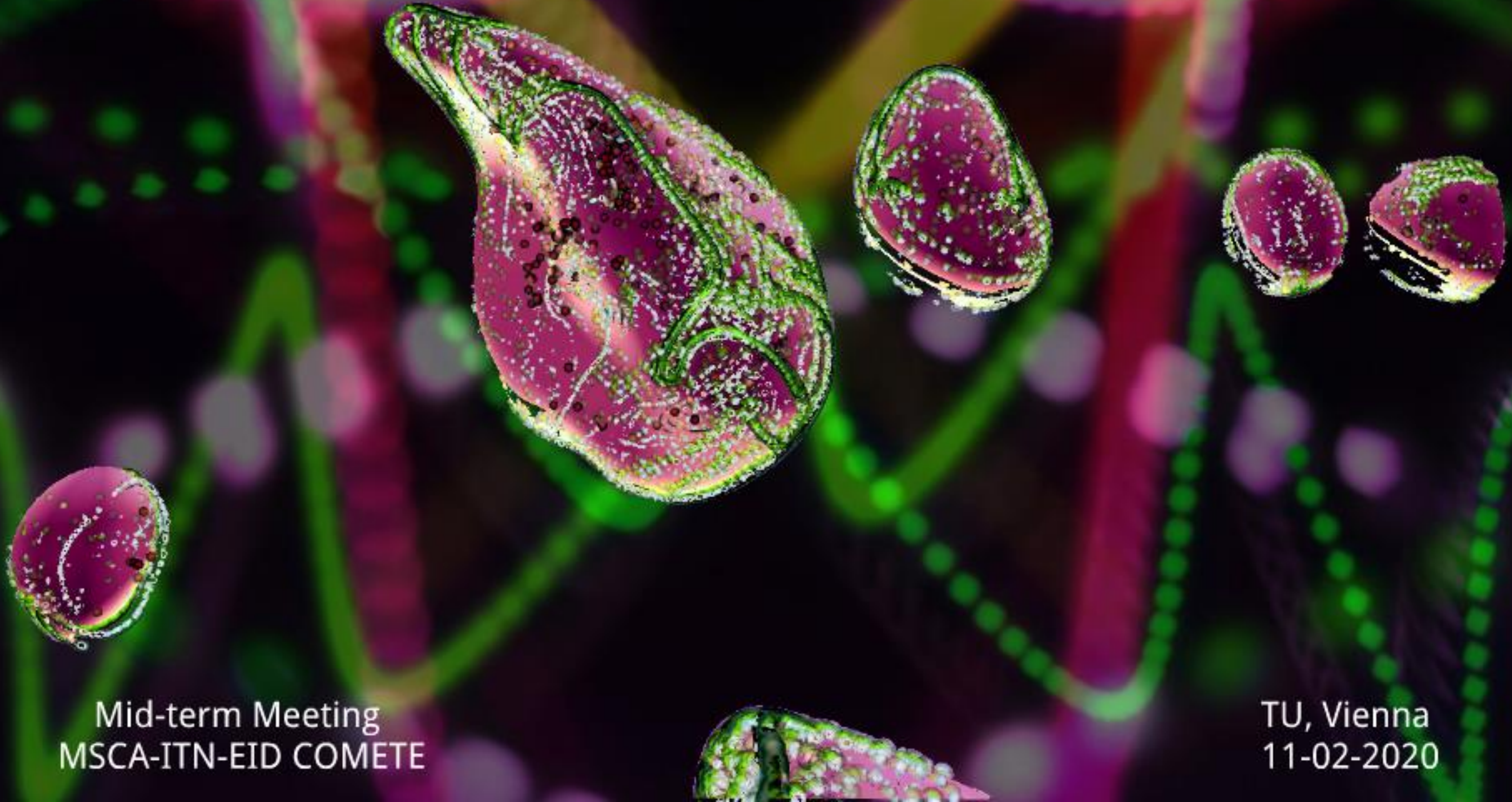
Simulation of particle-droplet interaction in turbulent three-phase flows

Work package 3

Phd Student: Kevin Miranda

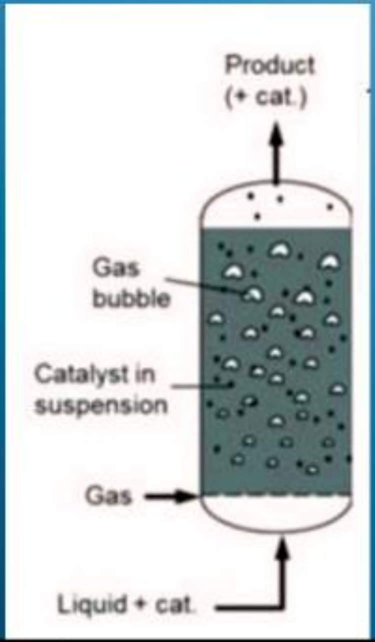
Supervisor: Cristian Marchioli



Mid-term Meeting
MSCA-ITN-EID COMETE

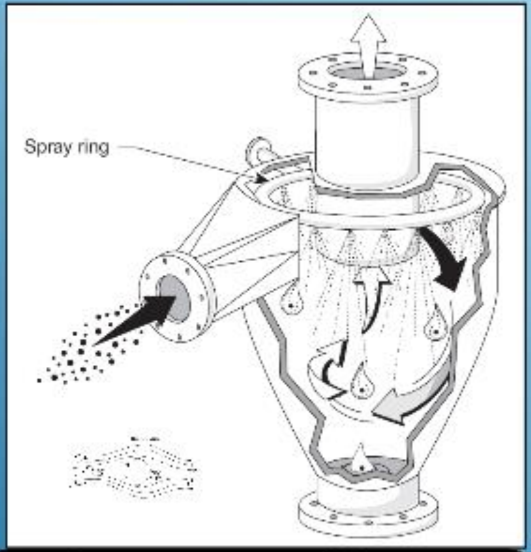
TU, Vienna
11-02-2020

Motivation



a)Slurry reactor

Jiulong Sun (Thesis 2014)



b)Spray scrubber

Entry #: V0016

Raindrop impact on a sandy surface

Runchen Zhao, Qianyun Zhang, Hendro Tjugito, and Xiang Cheng

Department of Chemical Engineering and Materials Science, University of Minnesota

C) Liquid marbel

Runchen Zhao(Thesis 2014)

Introduction
Approach
Simulation
Next Steps

COMETE

UNIVERSITÀ DEGLI STUDI DI UDINE

EURO HEAT PIPES

Objectives

Receive training Euler-Lagrange methods for industrial app

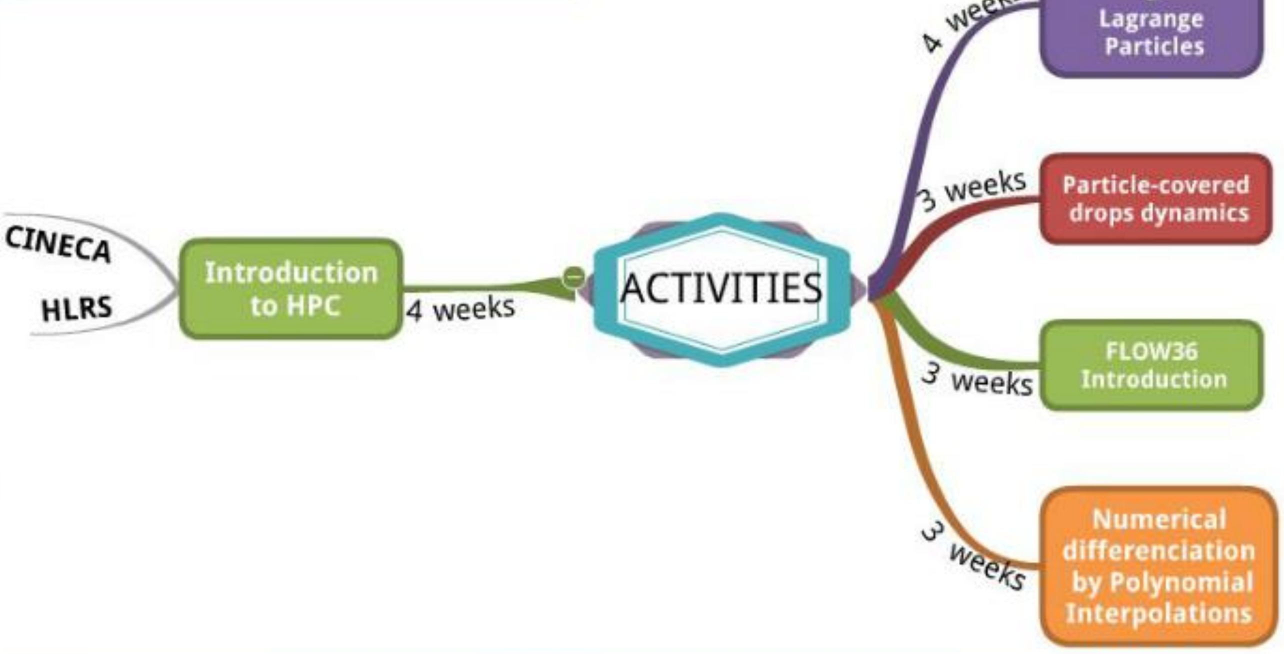
Generate a computationally efficient solver three-phase flow

Test a multi-scale approach (Dual Grid)

droplet-interface capture

Particle Lagrangian Tracking

Activities carried so far



CINECA

HLRS

Introduction to HPC

4 weeks

ACTIVITIES

4 weeks

Phase field & Lagrange Particles

3 weeks

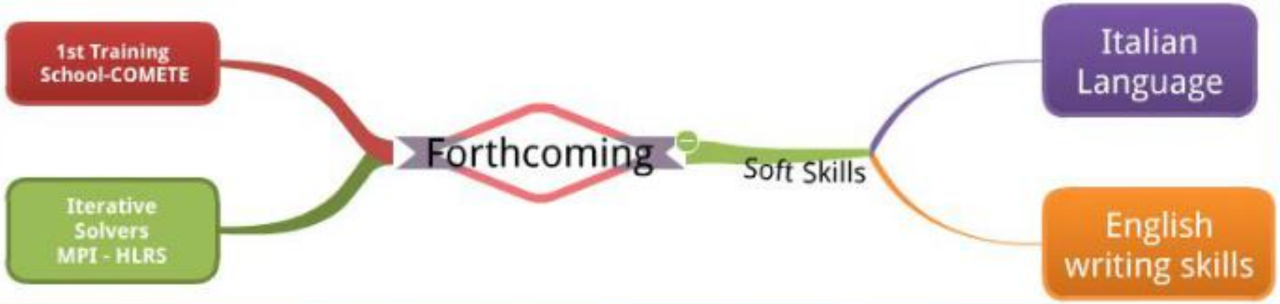
Particle-covered drops dynamics

3 weeks

FLOW36 Introduction

3 weeks

Numerical differenciation by Polynomial Interpolations



1st Training School-COMETE

Iterative Solvers MPI - HLRS

Forthcoming

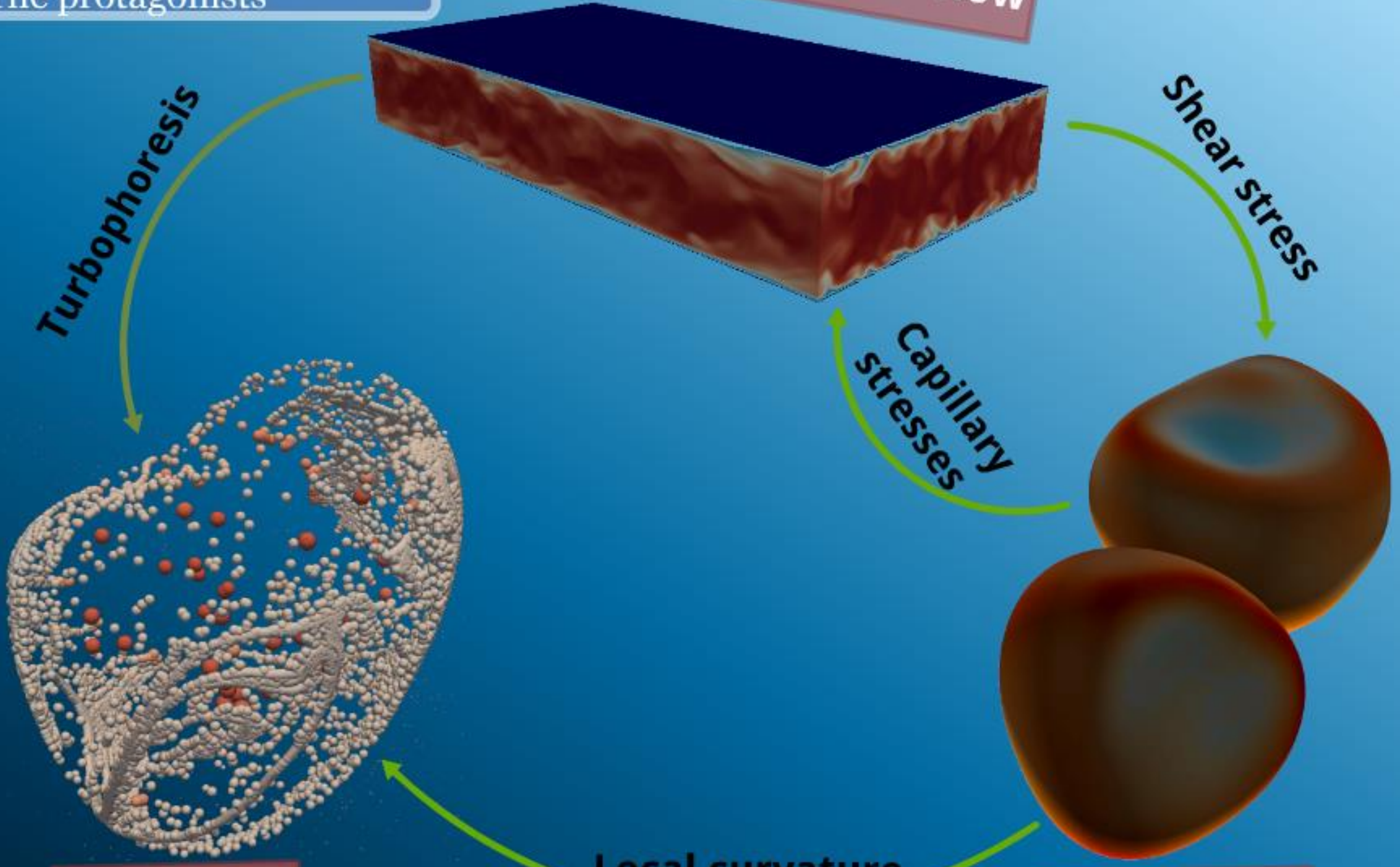
Soft Skills

Italian Language

English writing skills

Three phase flows

The protagonists



Turbulent flow

Shear stress

Capillary stresses

Turbophoresis

Local curvature

Particles

Droplets

Continuity and Momentum eq.

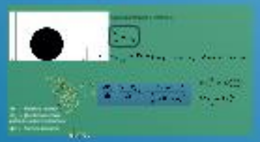
$$\nabla \cdot u = 0$$

$$\rho\left(\frac{\partial u}{\partial t} + (u \cdot \nabla) u\right) = -\nabla p + \mu \nabla^2 u$$

$$u_1 \cdot n - u_2 \cdot n = 0$$ Velocity B.C

$$T_1 \cdot n - T_2 \cdot n = \kappa \sigma n - \nabla_s \sigma$$ Stress Tensor B.C

- Dispersed Multiphase Flow
  - Carrier Phase
    - Continous Approach
    - Sharp Approach
  - Two dispersed Phase
    - Droplet laden flow
      - Interface Tracking
        - Front Tracking
        - IBM
      - Interface Capturig
        - Phase Field
        - Level Set
        - VoF
    - Particle laden Flow
      - Point wise simulation
        - Lagrangian particle Tracking
      - Fully Resolved Simulation



Dispersed
ultiphase Flow

- Two dispersed Phase
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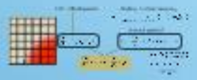
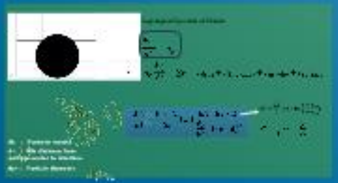
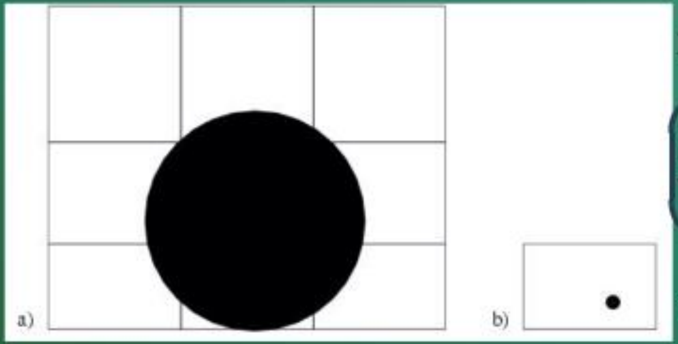




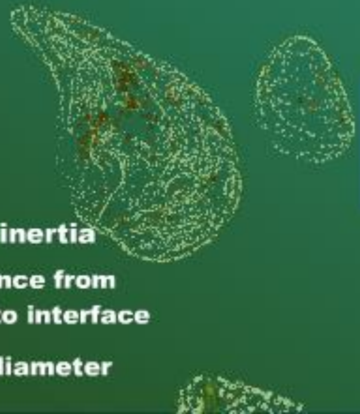
Lagrangian particle Tracking



Lagrangian Equation of Motion

$$\boxed{\frac{\partial x_p}{dt} = u_p}$$

$$m_p \frac{\partial v_p}{\partial t} = \sum F = F_{\text{drag}} + F_{\text{Buoyancy}} + F_{\text{gravity}} + F_{\text{surface}}$$



$$\frac{du_p}{dt} = \frac{u - u_p}{St} f_D + \frac{6A * Re * d^+}{\frac{\rho_p}{\rho_f} * We * d_p^{+3}}$$

$$d^+ = \frac{\sqrt{2}}{2} * Ch * ln\left(\frac{1 + \varphi_{pp}}{1 - \varphi_{pp}}\right)$$

$$d_p^{+3} = \sqrt{18 * St * \frac{\rho_p}{\rho_f}}$$

St : Particle inertia

d+ : Min distance from particle center to interface

dp+ : Particle diameter

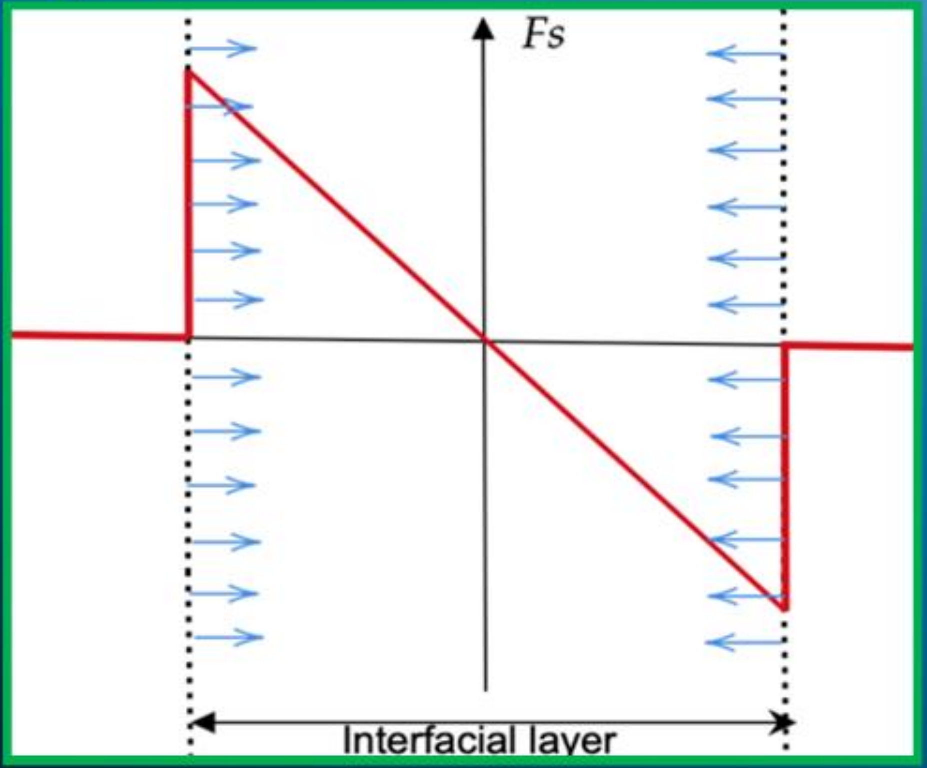
Particle-interface interaction model:

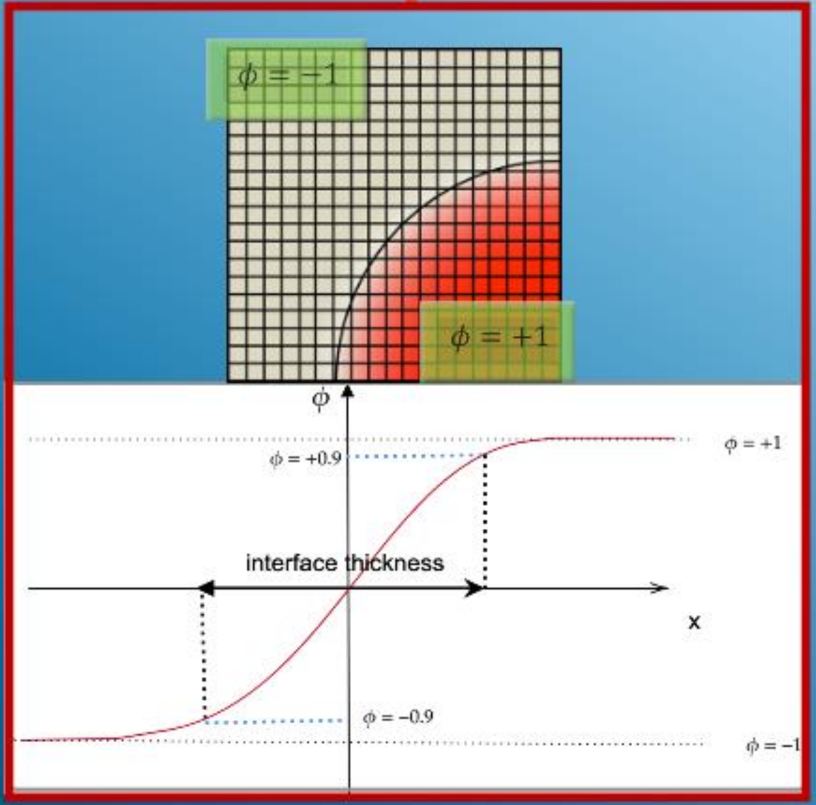
The "surface tension" force

$$\vec{F}_s = \begin{cases} A\pi\sigma d\vec{n} & \text{if } |\phi_{pp}| \le \phi^* \\ 0 & \text{if } |\phi_{pp}| \ge \phi^* \end{cases}$$

O'Brien, J. Colloid Interface Sci., 1996
Ettelaie & Lishchuk, Soft Matter, 2015
Gu & Botto, Soft Matter, 2016)

threshold value of the phase indicator





Introduction
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3D simulation

Settings

1

Simulation Parameter :

Grids= 512*256*257 (N_x, N_y, N_z)

Size= $4\pi * 2\pi * 2(L_x, L_y, L_z)$

$Re_\tau = 150$

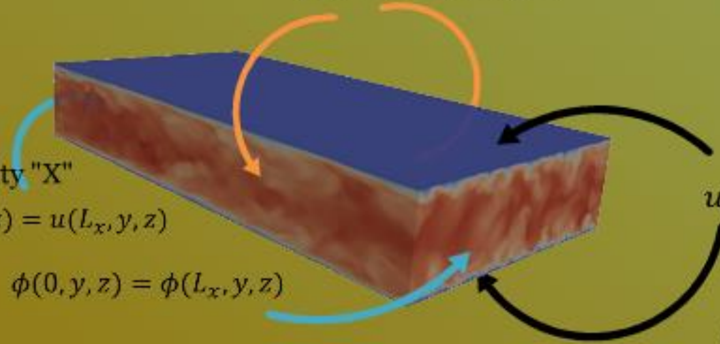
$Pe = 50$

$We = 0.5$

St = 0.2, 0.4, 0.8

2

Boundary condition



Periodicity "Y"

$u(x, 0, z) = u(x, L_y, z)$

$\phi(x, 0, z) = \phi(x, L_y, z)$

Periodicity "X"

$u(0, y, z) = u(L_x, y, z)$

$\phi(0, y, z) = \phi(L_x, y, z)$

No-Slip

$u(x, y, \pm 1) = 0$

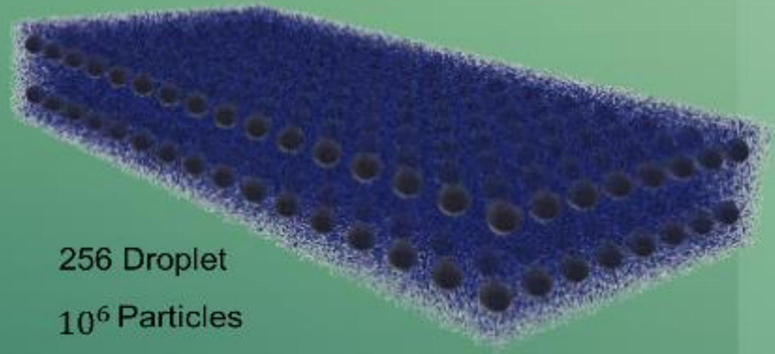
$\frac{\partial \phi}{\partial z}(x, y, \pm 1) = 0$

$\frac{\partial^3 \phi}{\partial z^3}(x, y, \pm 1) = 0$

3

Initialization

Fully Developed Turbulent Flow

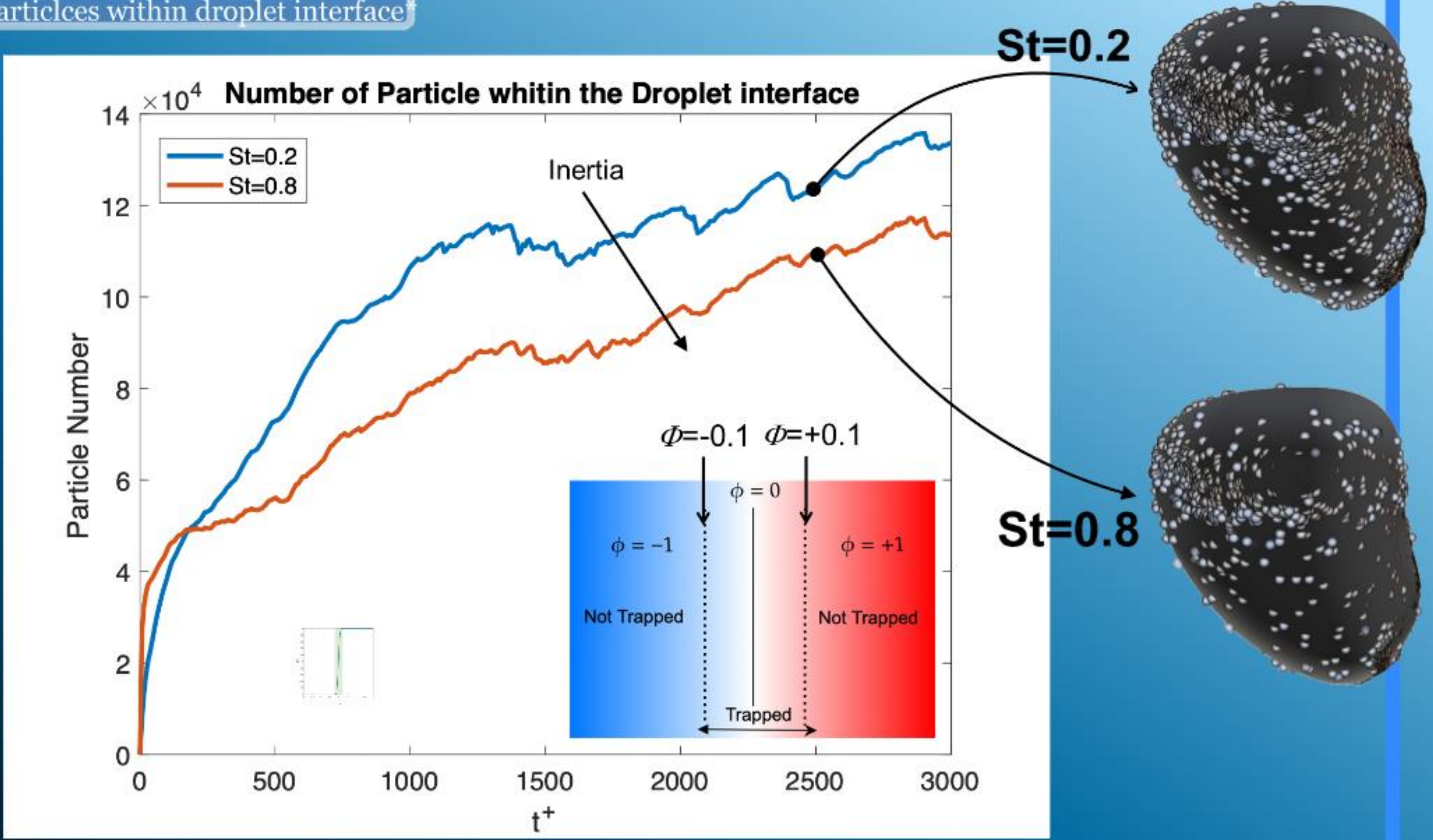


256 Droplet

10^6 Particles

Results

Particlces within droplet interface*



*aknowledgments Arash Hajisharifi

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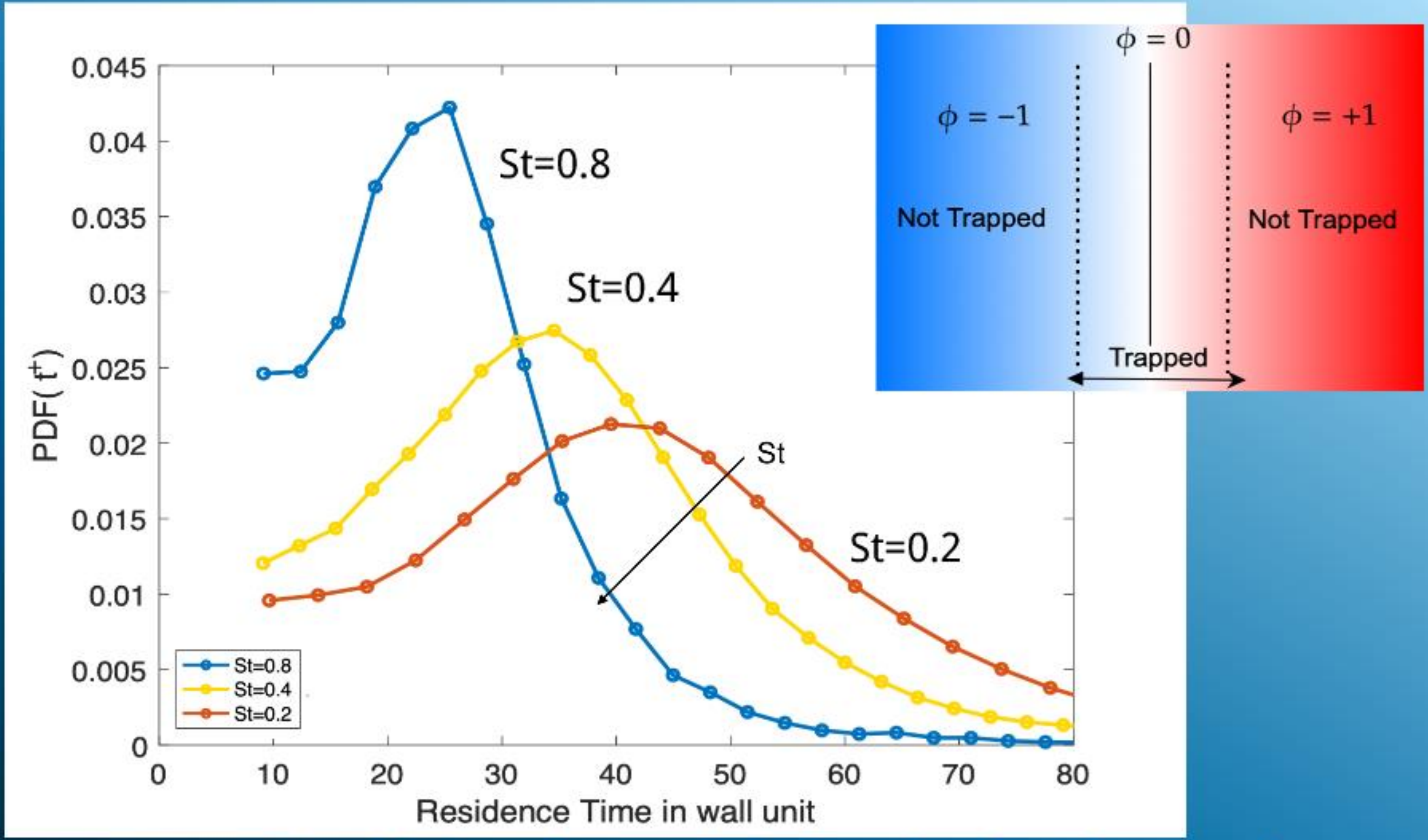
Results

PDF of particle residence time

Φ=-0.1 Φ=+0.1



The higher the particle inertia, the shorter the particle residence time

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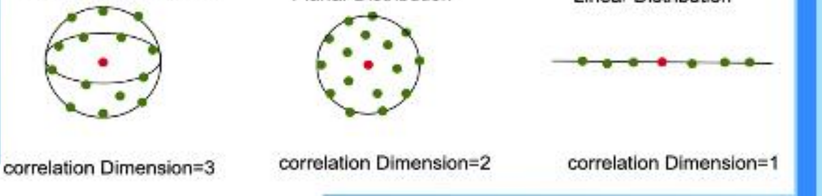
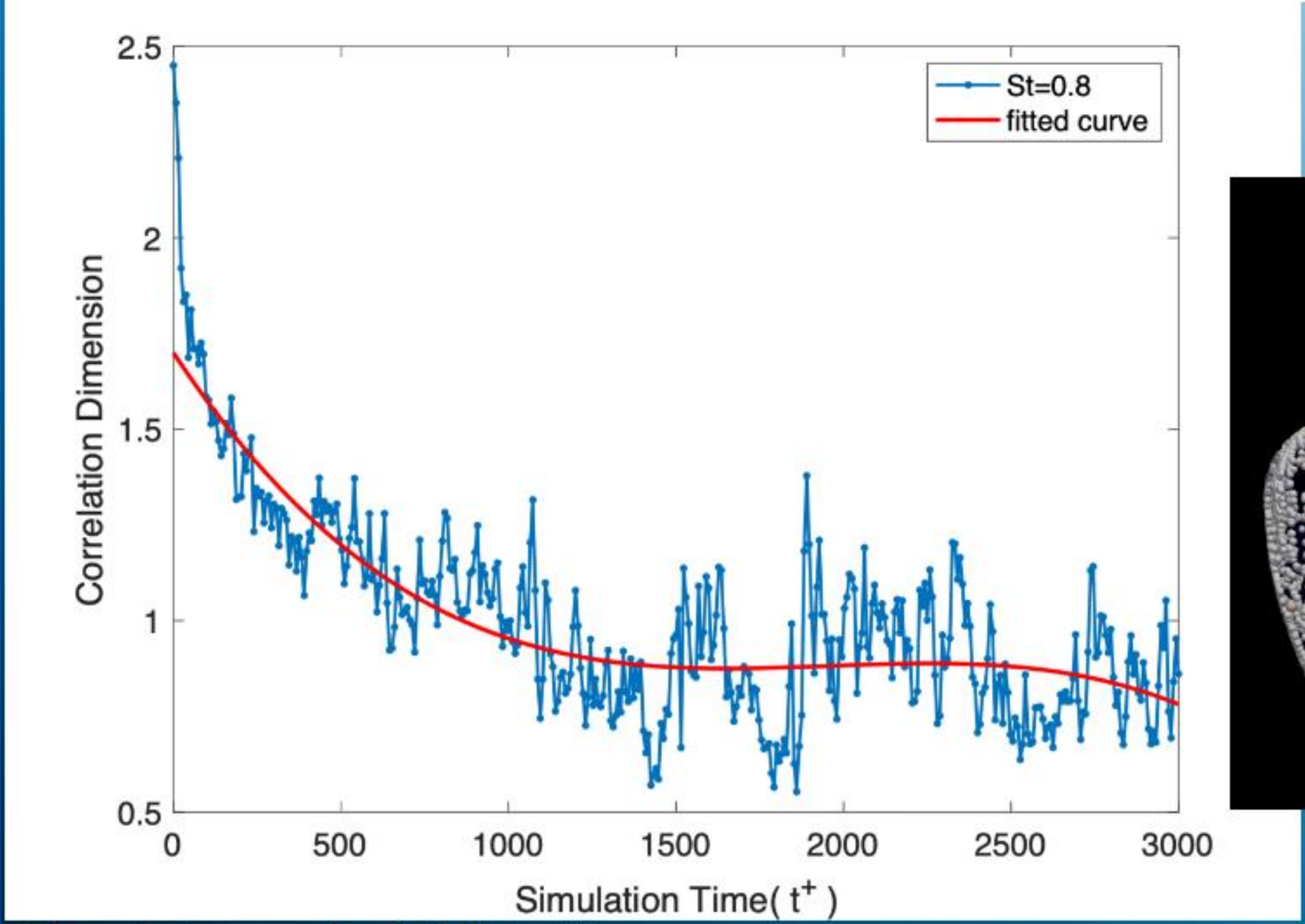
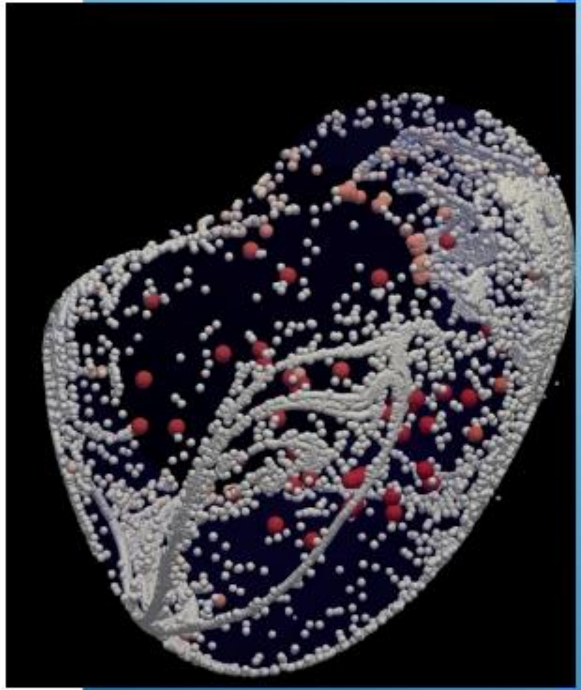
FOCUSKY

Results

Particle distribution within interface







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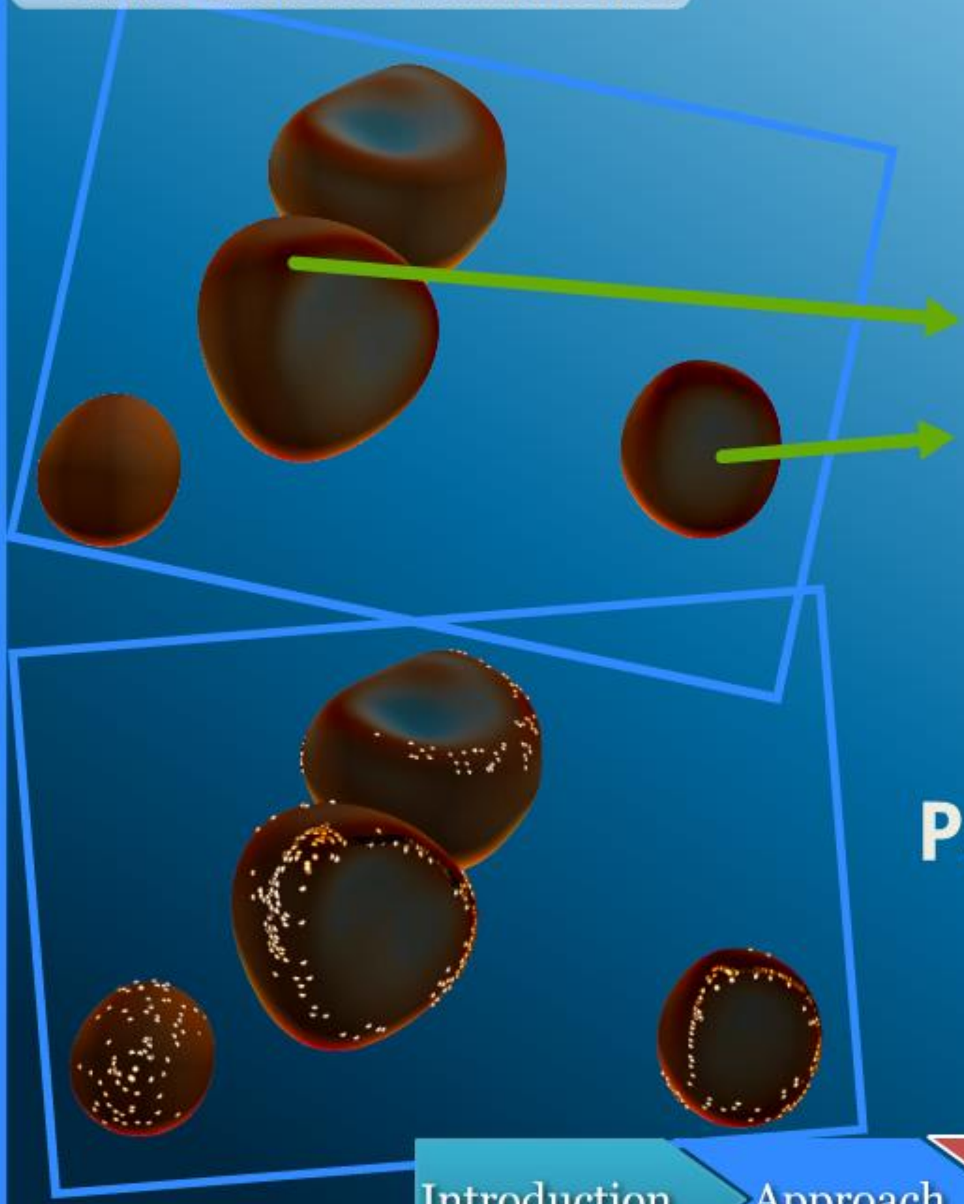
Introduction Approach Simulation Next Steps

Results

Particle distribution within interface



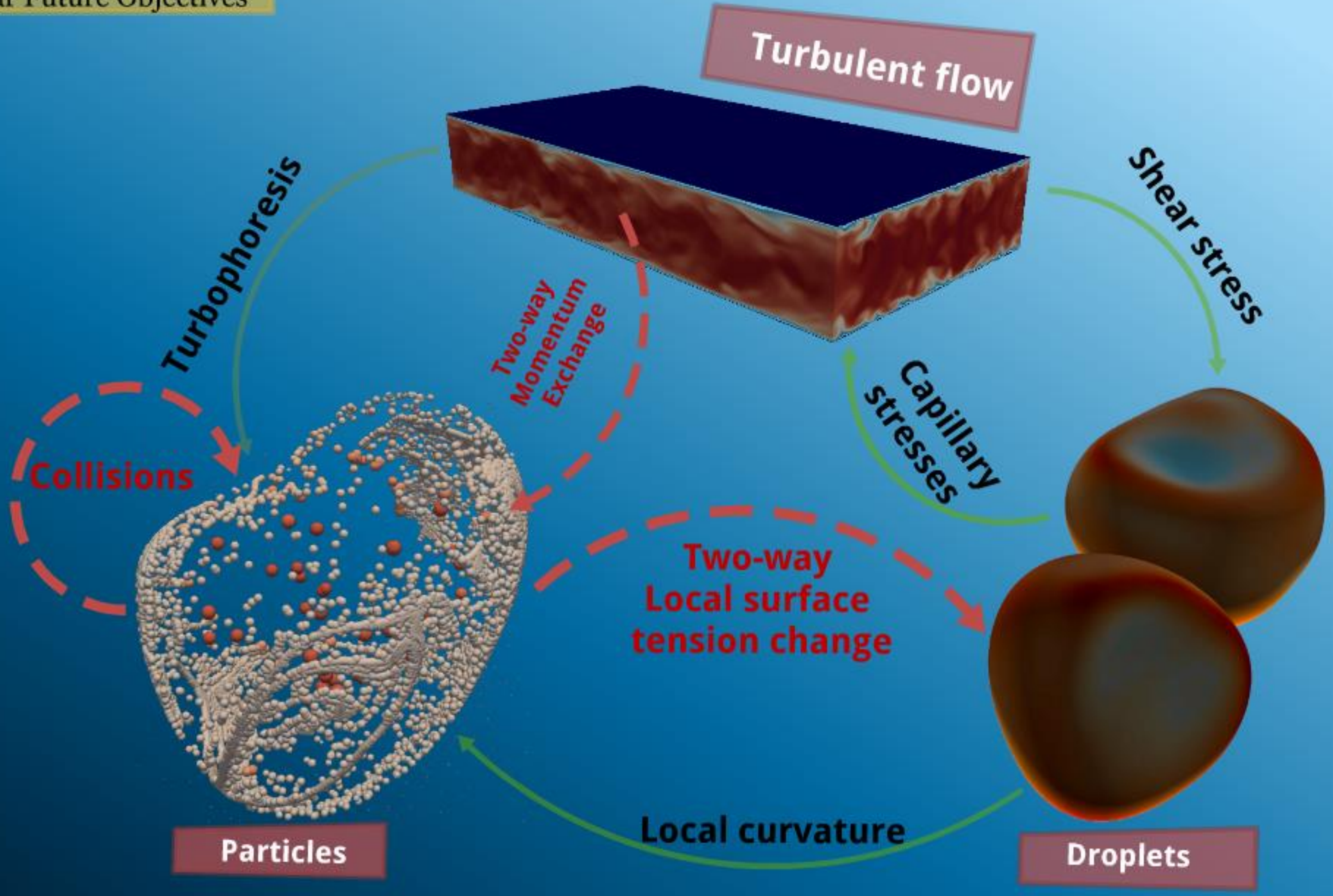
$$K = \nabla . \frac{\nabla \phi}{|\nabla \phi|}$$

Convex regions → positive curvature

Concave regions → negative curvature

Particles concentration increases with curvature

Near Future Objectives



Turbulent flow

Turbophoresis

Two-way
Momentum
Exchange

Shear stress

Capillary
stresses

Collisions

Two-way
Local surface
tension change

Local curvature

Particles

Droplets

TO BE CONTINUED ...

Thanks for your
kind atention

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