JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

How fast do bubbles rise in strong turbulence?

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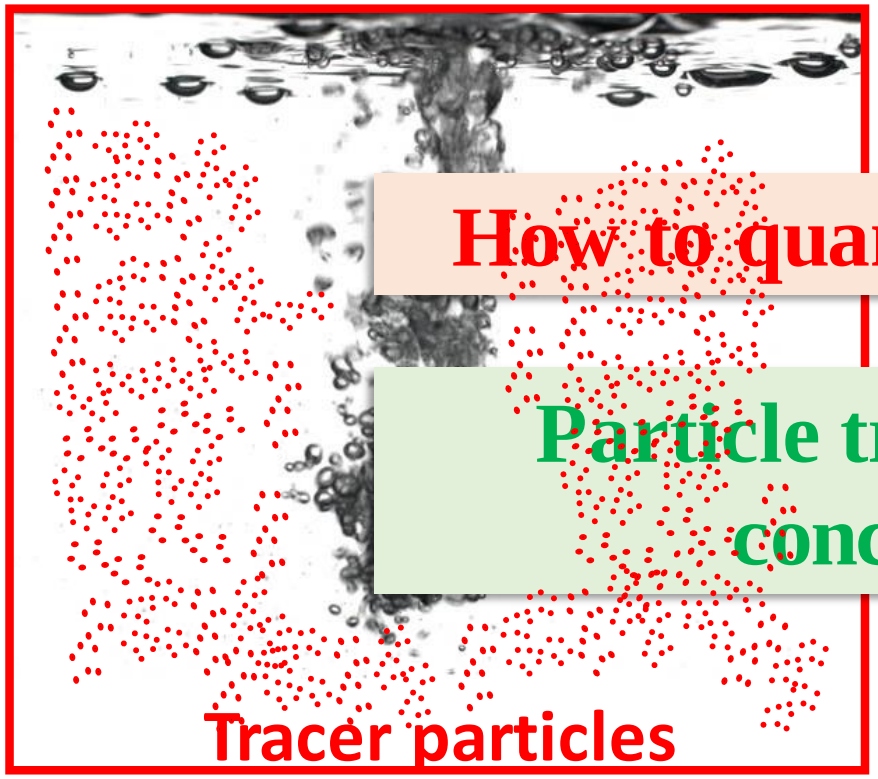
NSF

Challenge in multi-phase flow experiments:

Flow Quantification

Challenges of experimentally studying multiphase flow



How to quantify these flows?

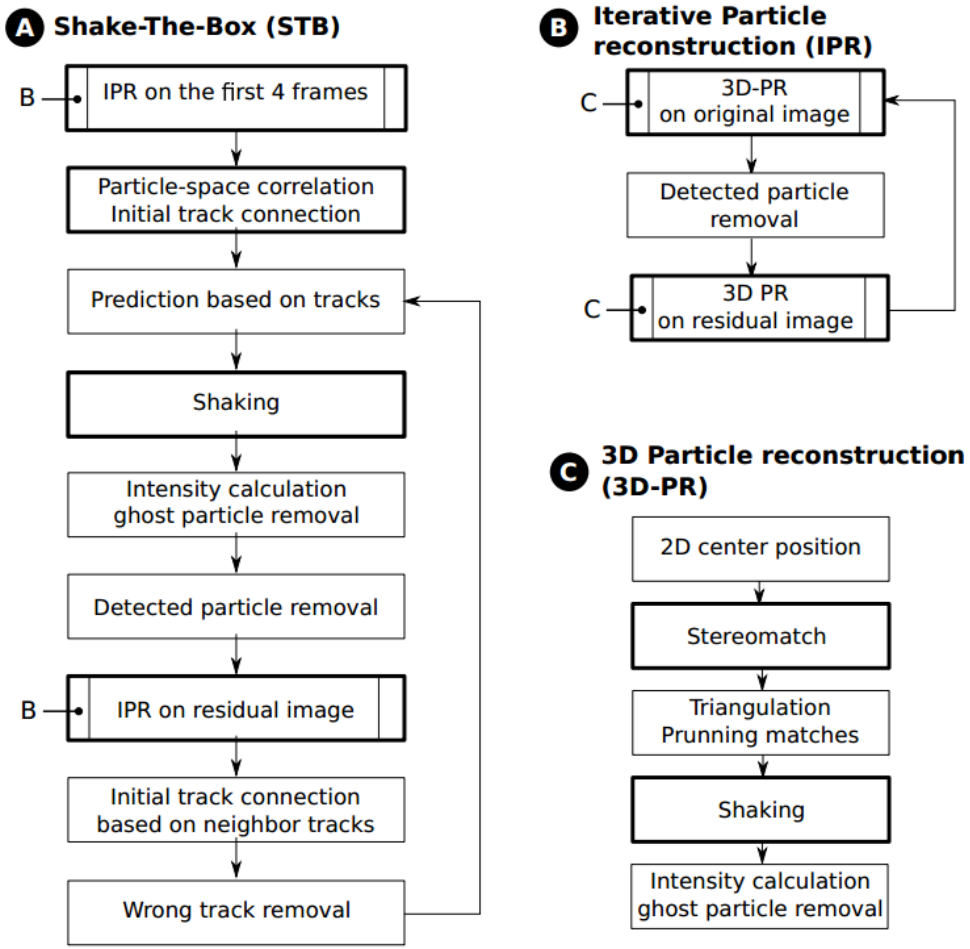
Particle tracking at high concentration

Liquid-gas interaction
(like air bubbles in water)

Solid-gas interaction
(like fluidized beds)

Carrier phase flow quantification

Quantifying the flow using particle tracking velocimetry (PTV)



Code structure:

Main Class:
1. Calibration
- Stereomatch
- Shaking

2. IPR
- Calibration

3. STB
- Predictive-field
- Shaking
- IPR

Common Class:
- Camera
- OTF
- Frame
- Position
- Track

Flow chart of STB based on Schanz, Gesemann, Schröder 2016
Wieneke 2013, and Ouellette, Xu, Bodenschatz 2006

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JHU-NI-LAB / ShakeTheBox OpenSTB

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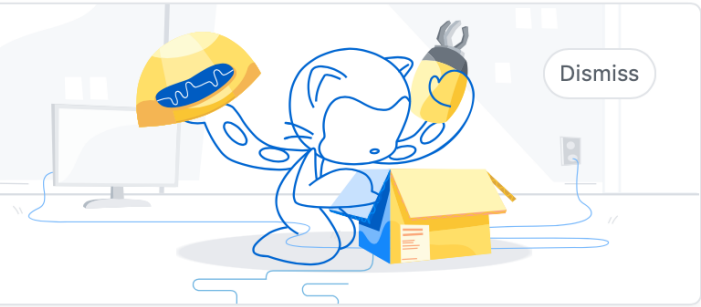


Open-source C++ code for Shake-the-box, particle tracking algorithm

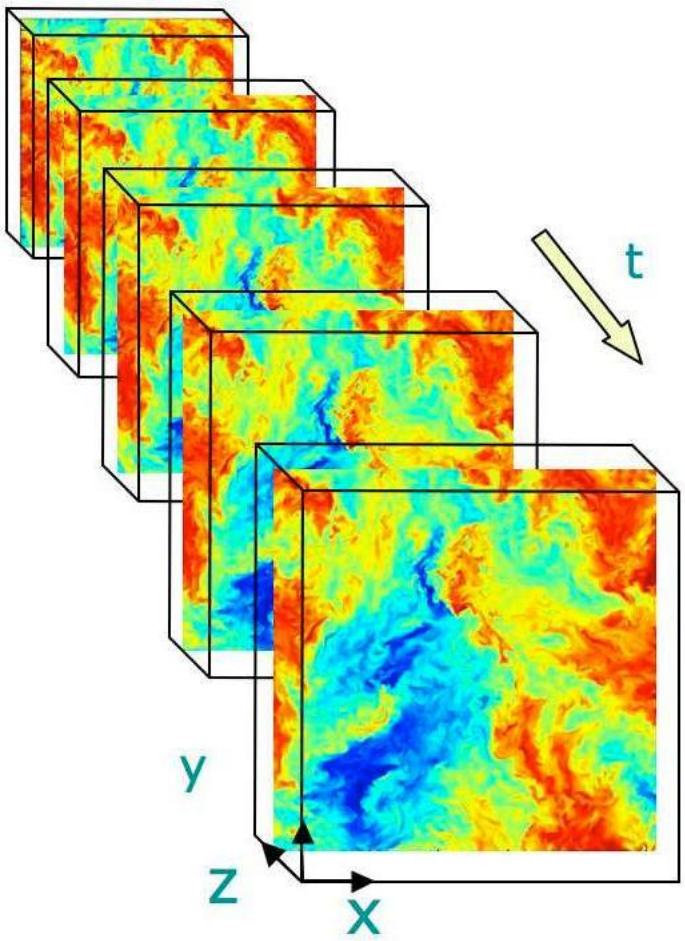
82 commits 2 branches 0 releases 3 contributors

Branch: Parallelization New pull request Find File Clone or download

JHU-NI-LAB Update the email address Latest commit e32047f 18 minutes ago

.metadata/.plugins/org.eclipse.cdt...	Fix the bug when loading previous tracks	9 months ago
.settings	Fix a bug in the particle removing after IPR on residual.	3 months ago
Data_analysis_process	Added MATLAB code for data preprocessing, such as generating the conf...	8 days ago

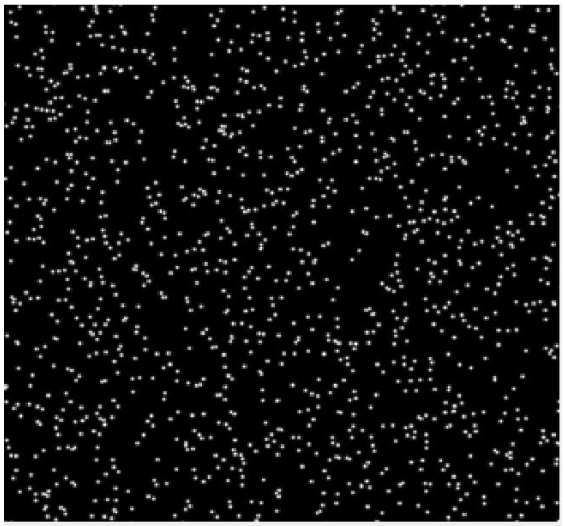
Platform to share: (a) code development

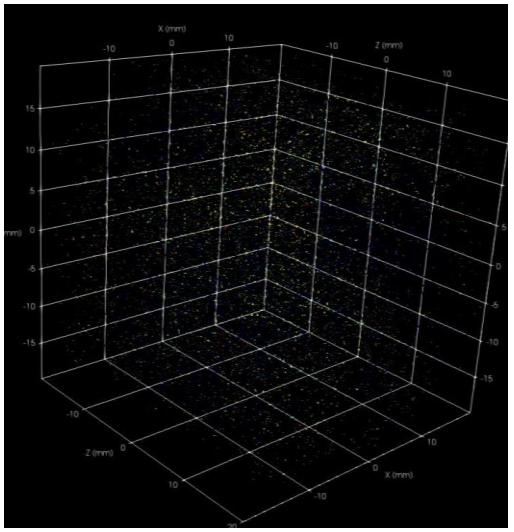


0.0125 ppp

Johns Hopkins Turbulence Database (JHTDB)

- Direct numerical simulation (DNS) using $1{,}024^3$ nodes
- The Taylor-scale Reynolds number fluctuates around $R_\lambda \sim 433$.
- One dataset ("fine") that stores every single time-step of the DNS, for testing purposes. Times available are for t between 0.0002 and 0.0198).





Open-source STB and its performance

Performance evaluation

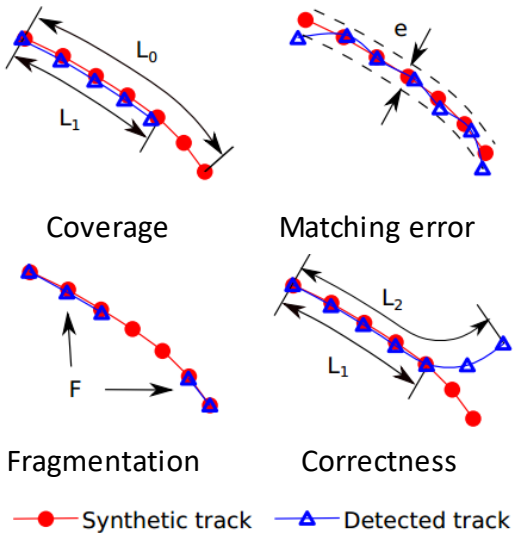


Image density	0.0125	0.025	0.05
Coverage	0.9996	0.9995	0.9991
Matching error (mm)	8.87e-4	0.0011	0.0012
Fragmentation	1.0309	1.0313	1.0020
Correctness	1	1	1

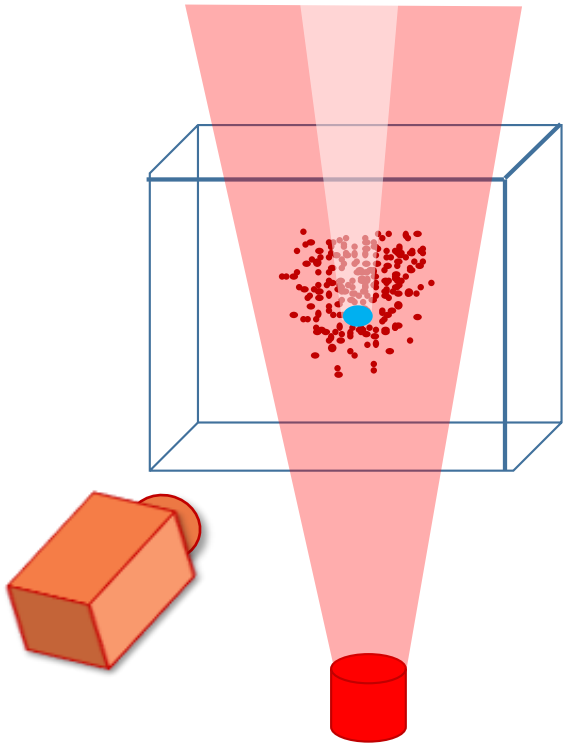
Open-source STB performs well

- Coverage is 0.9991 at 0.05 ppp, similar to 0.9986 reported in Schanz et al, 2016.
- Matching error is one order of magnitude smaller than the particle displacement of 0.06 mm.
- Fragmentation and correctness indices are close to 1, suggesting robust tracking results.

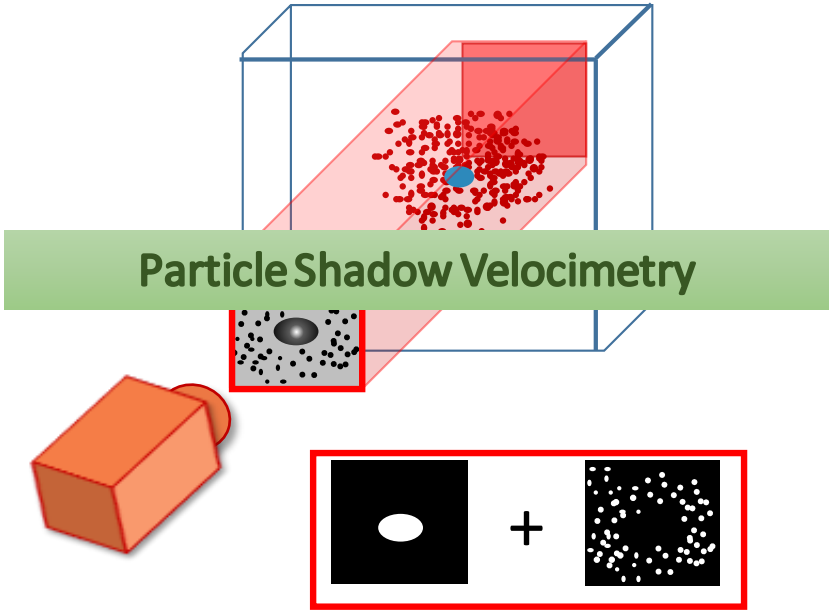
Flow quantification in multi-phase flow

Simultaneously quantify both the phases in 3D

Particle tracking on multi-phase flow



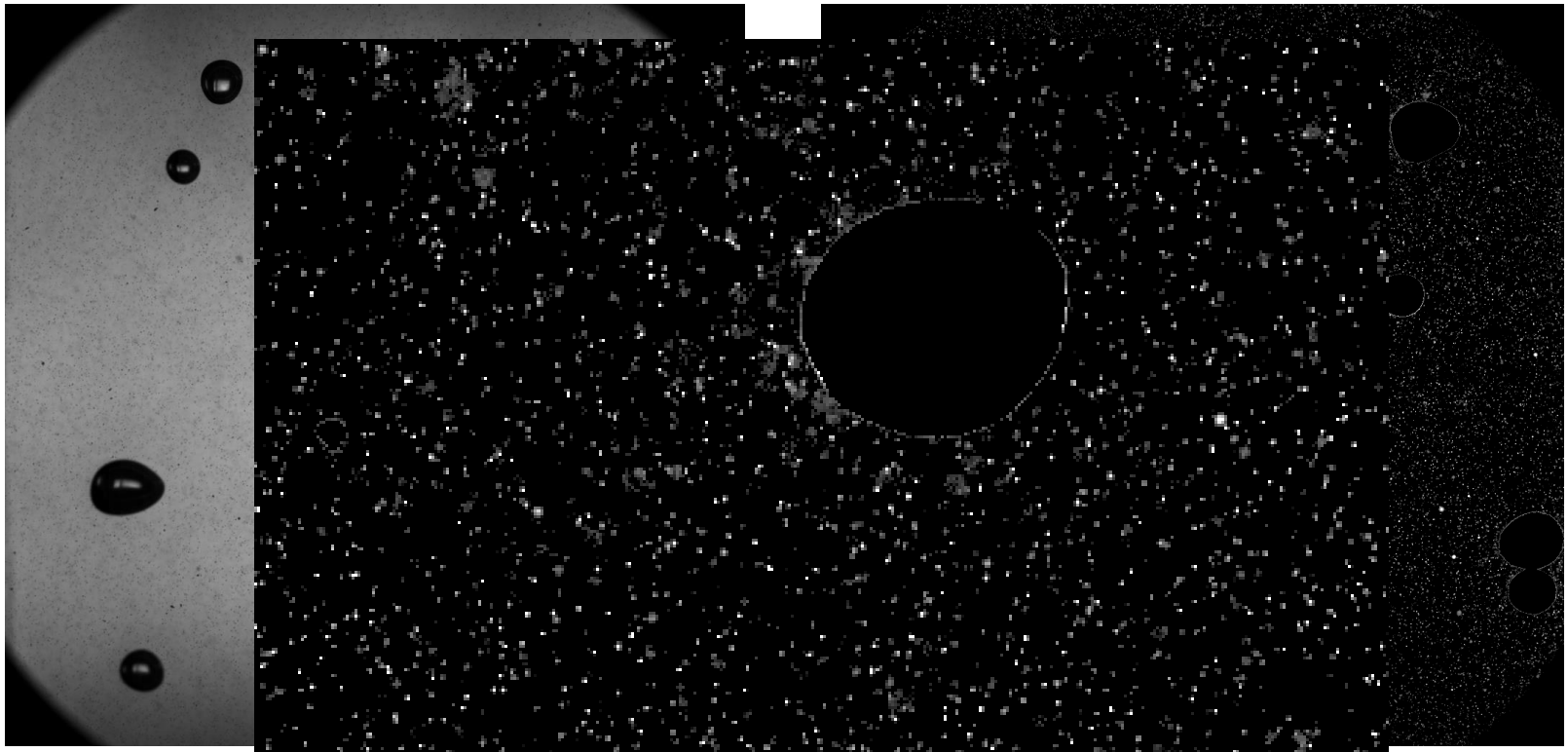
Using scattering



Using LED backlighting

*Cheap and bright, allow time-resolved measurements at 10 kHz

Image with bubbles and just tracers

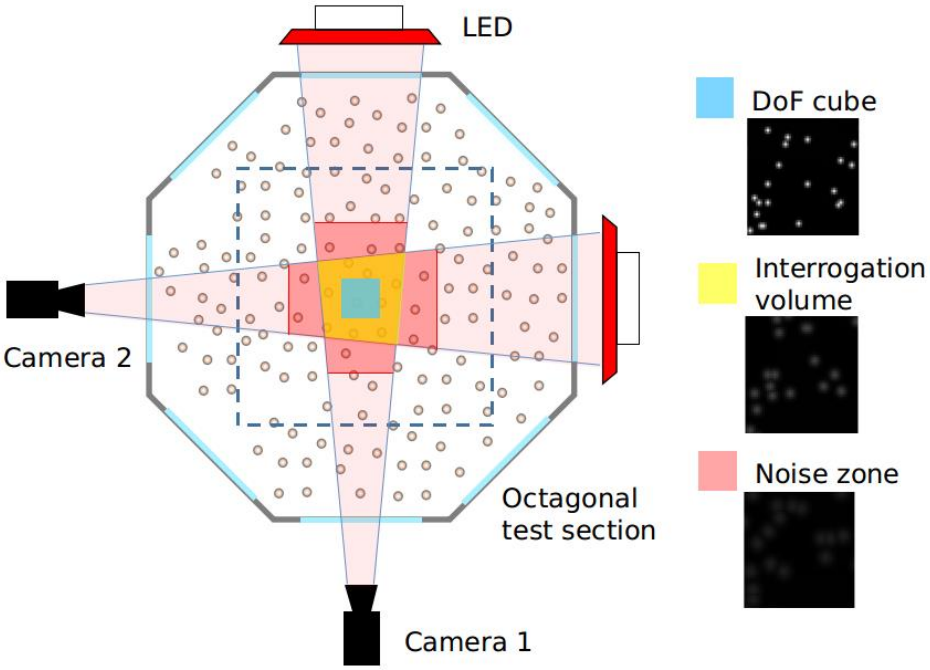


Raw ima

Blurring particles

Depth of field and noise zone

The size of noise zone (particles outside interrogation volume) is used to quantify the level of blurring effect to STB.



Based on the model of DoF by Allen and Triantaphillidou, 2012, and the model of particle image from Rossi et al., 2012:

$$\mathrm{DoF} \propto \frac{1}{D_a}$$

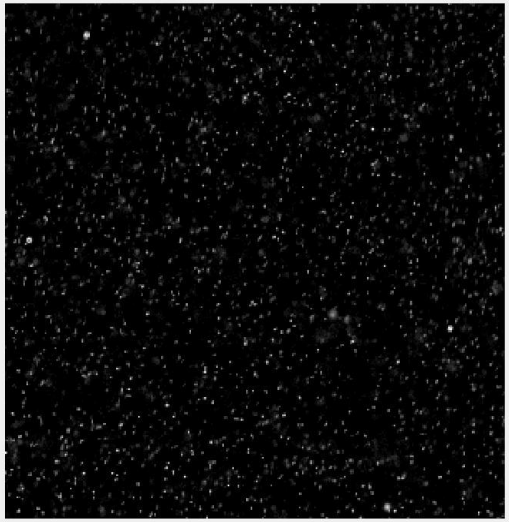
$$L_{noisy} \propto \frac{1}{D_a^2}$$

As one reduces the pinhole aperture size to gain DoF, the length of noise zone increases more.

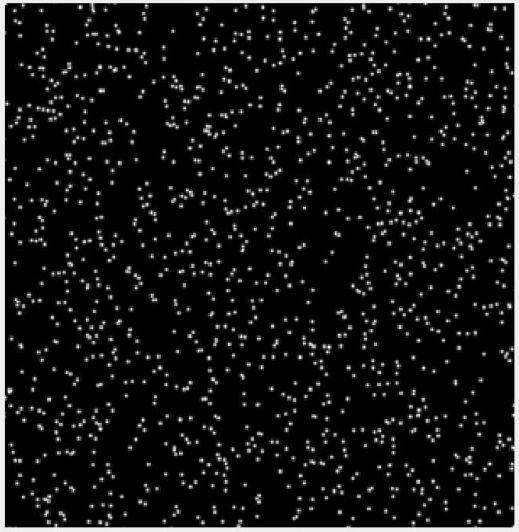
Open-source STB and its performance

Comparison of experimental and synthetic image

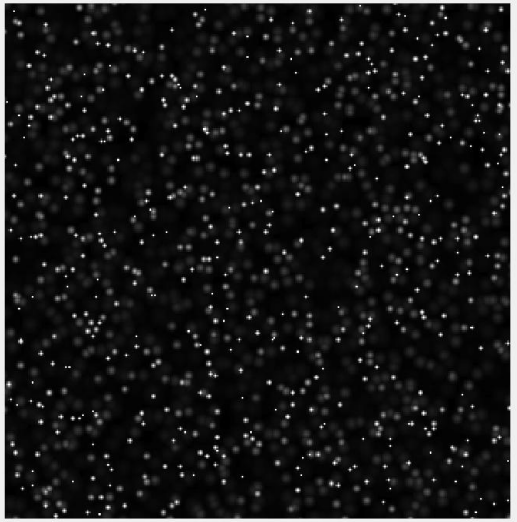
Experiment image:



Synthetic image (Ideal):



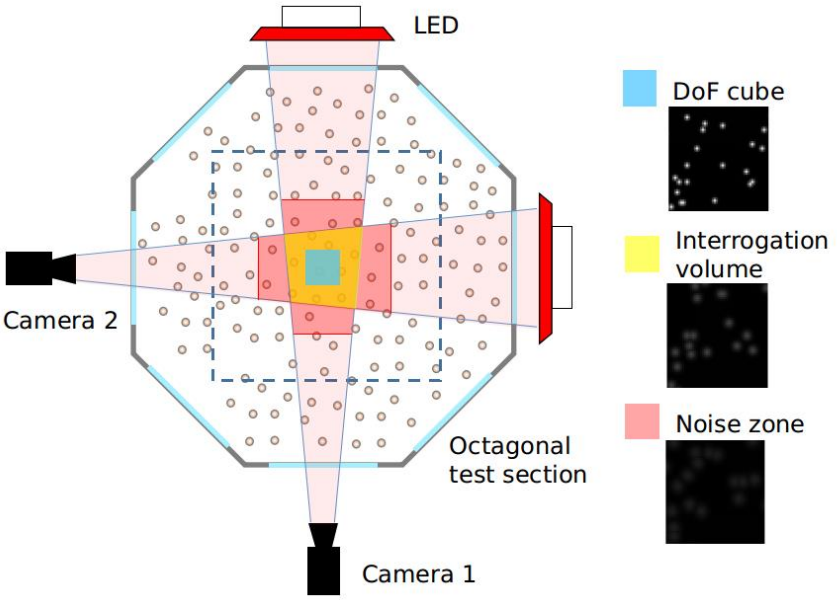
Synthetic image (Blurred):

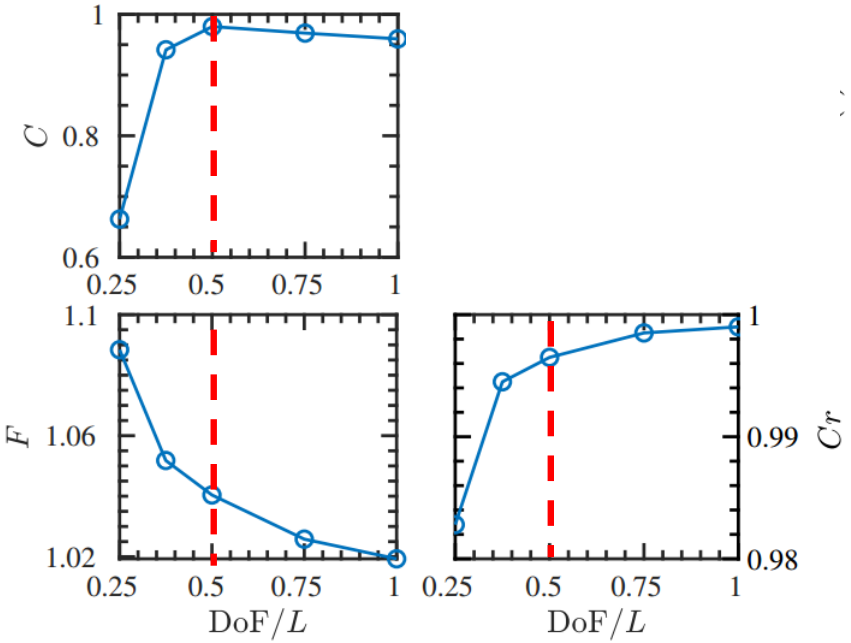


Noise due to blurred particles are different from the random noise on images

STB performance on noisy images

Varying Depth of field





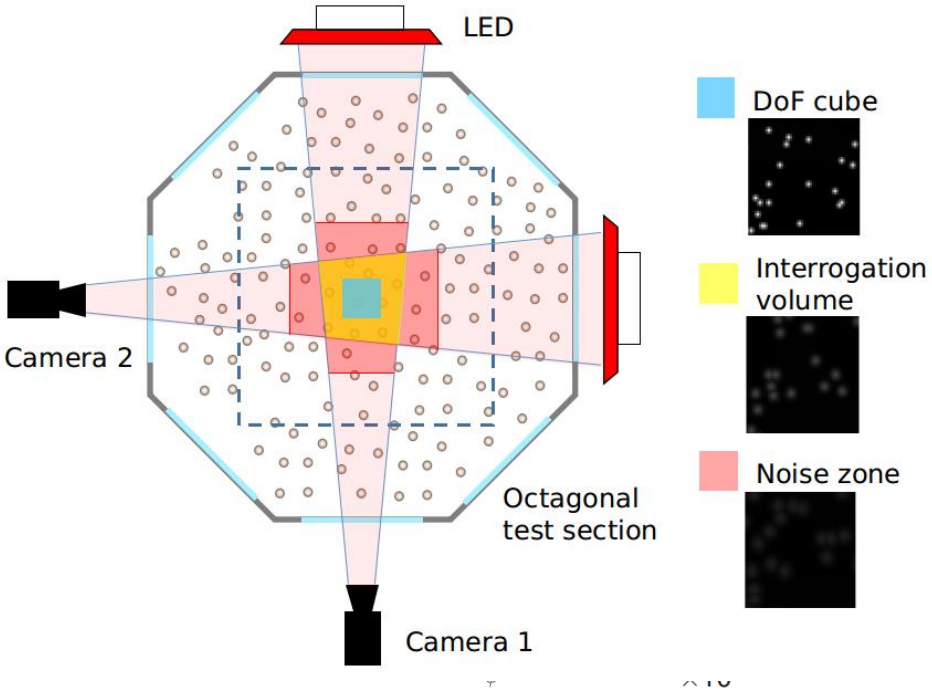
At DoF/L = 0.5, coverage C reaches its maximum, close to one.

At DoF/L = 0.5, there is a good balance between the track quality and the total processing time.

STB performance on noisy images

Concentration variations

Varying particle concentration at the same DoF/L = 0.5

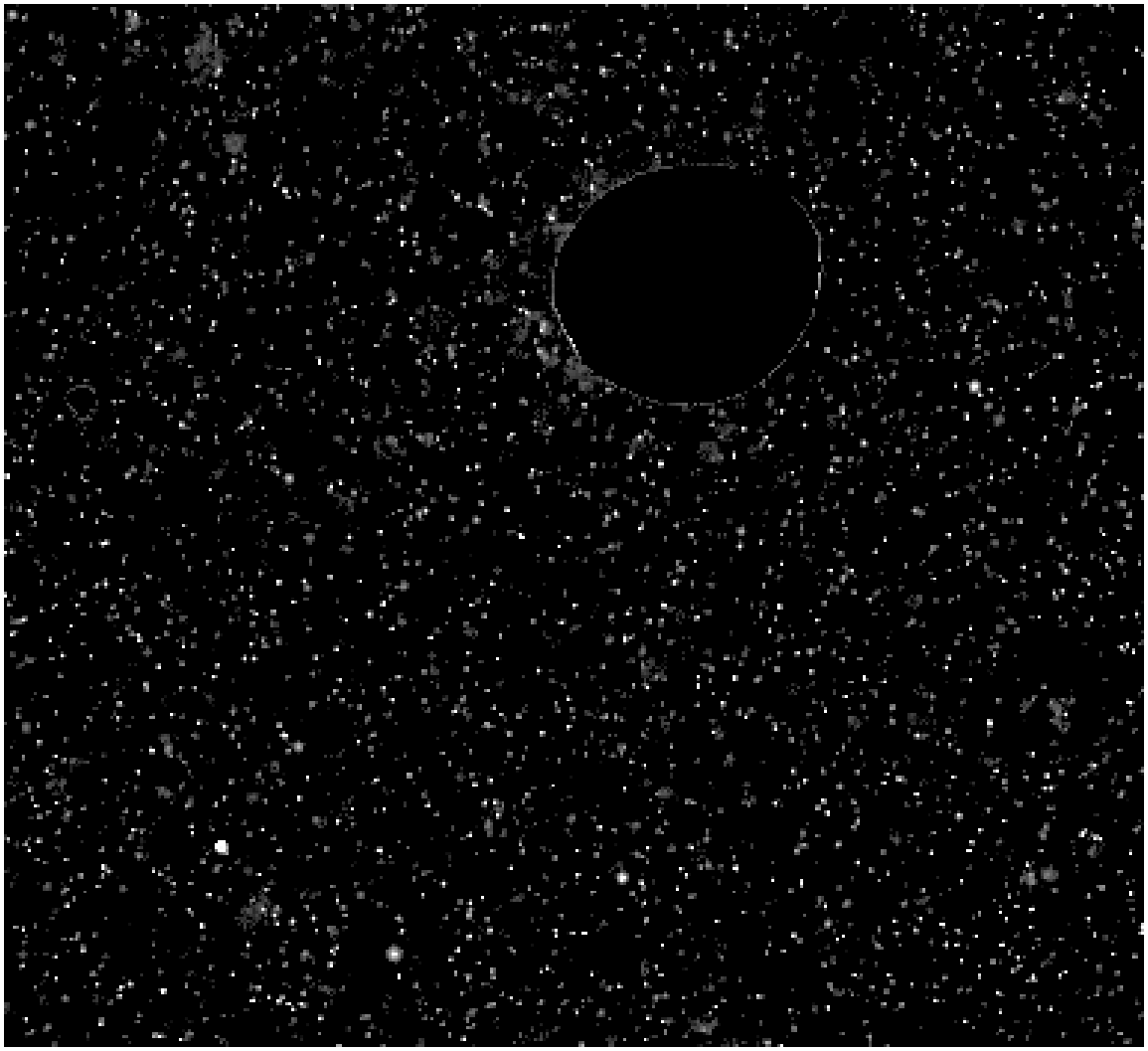


N_d: the number of STB-detected particles

N_t: the number of particles inside interrogation volume.
N_Φ: the number of particles on an image.

Nearly 95% tracks can be covered at N_t =27,500 (0.028 ppp)

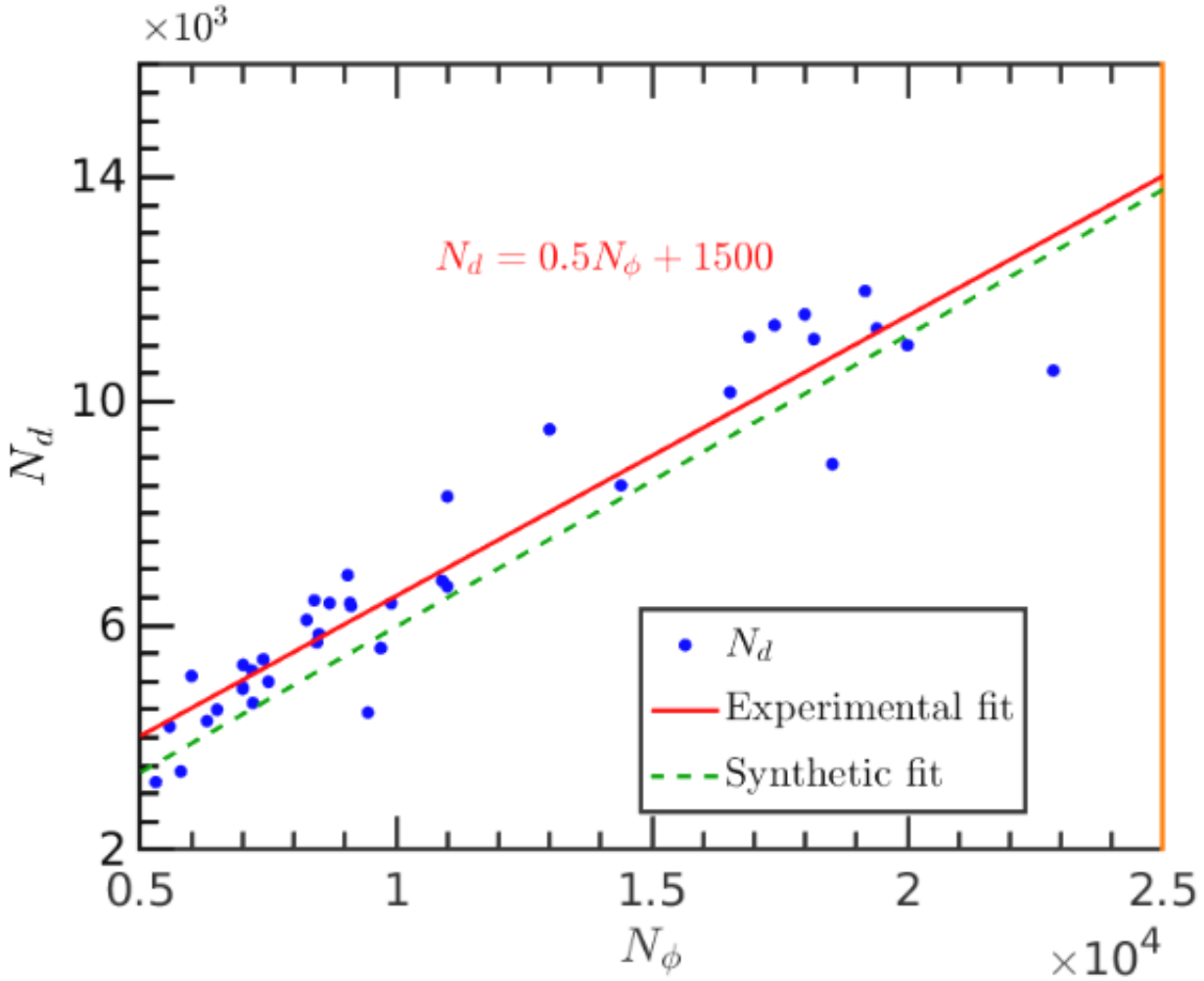
Image with bubbles and just tracers



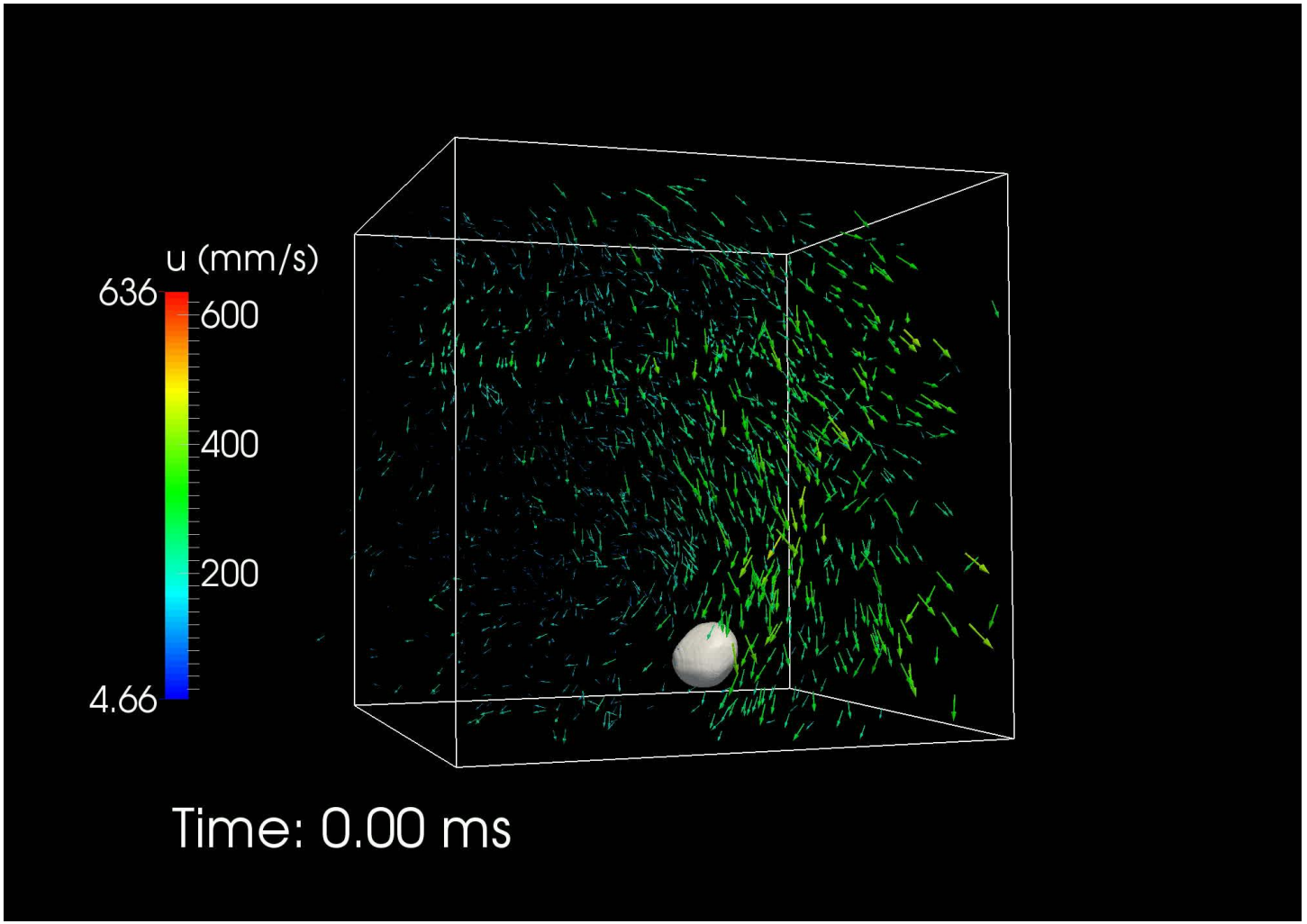
Experimental results

Relation between N_d and N_Φ

N_d : the number of STB-detected particles;
N_Φ : the number of particles on an image;

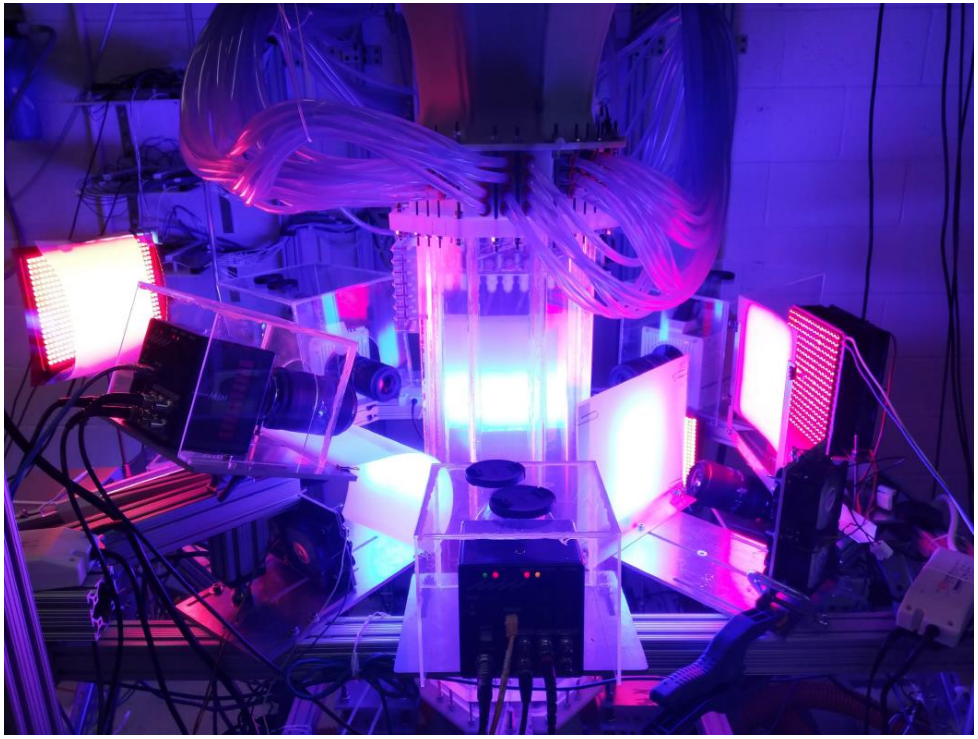


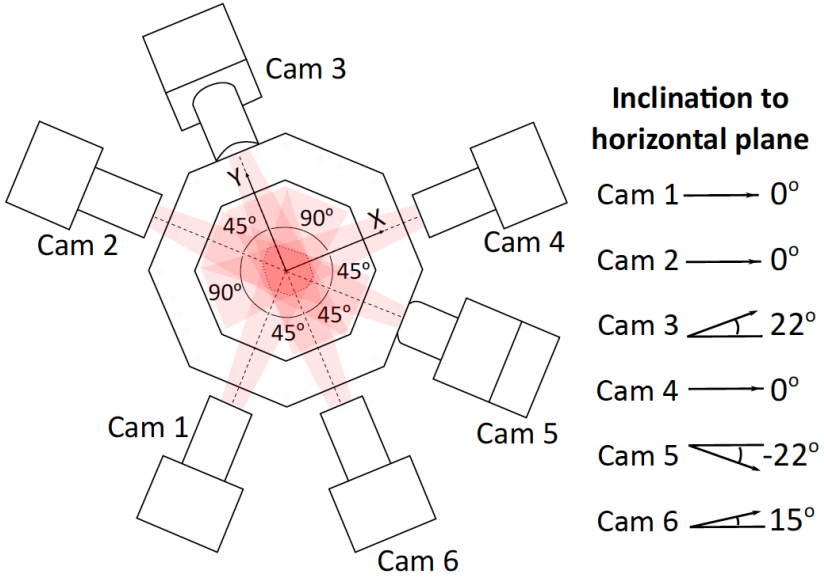
Experimental results



Applied to study bubble rise velocity

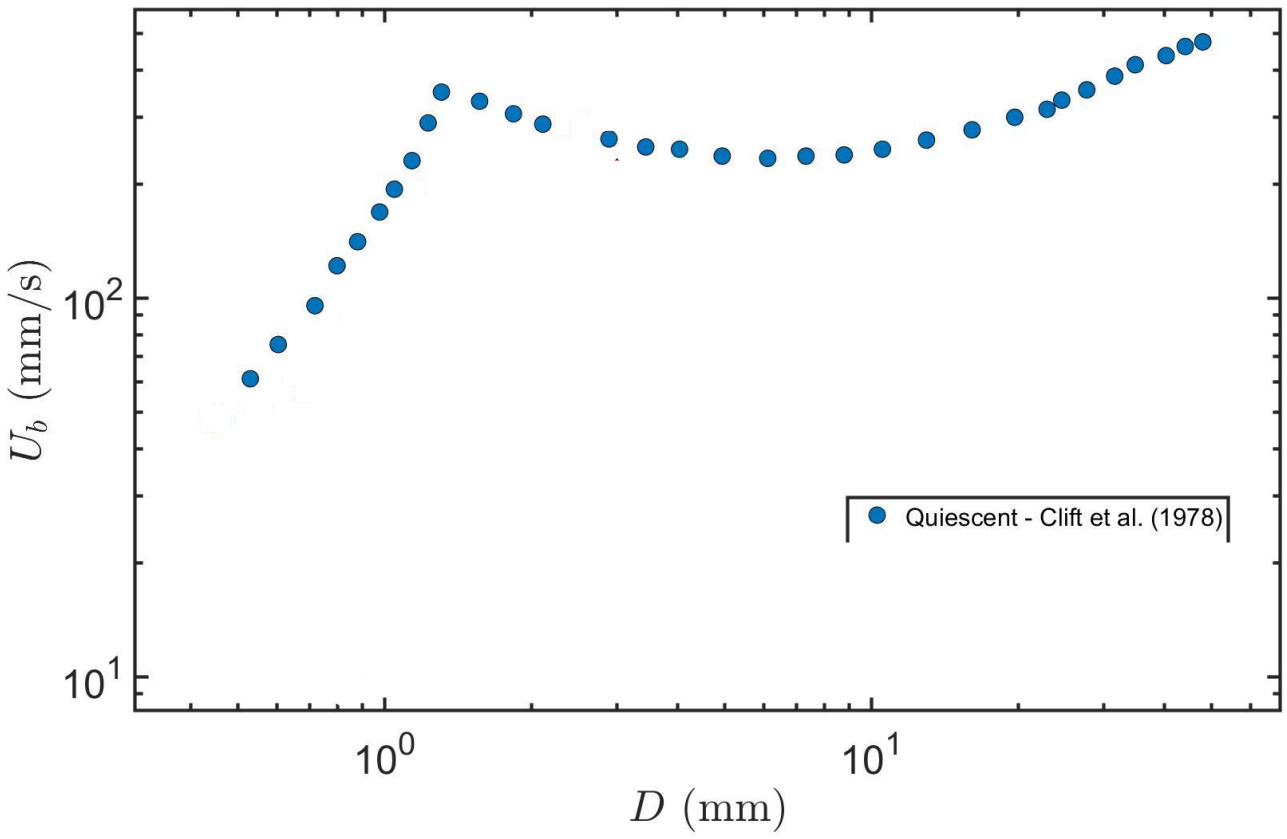
Flow visualization



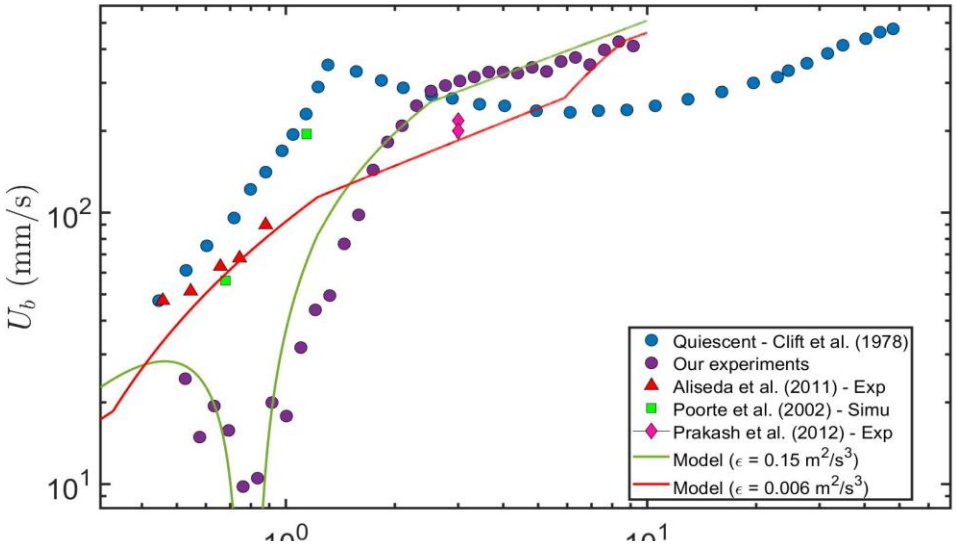


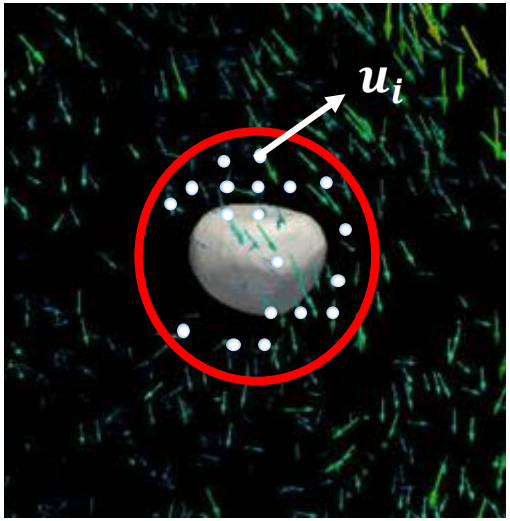
Four Photron AX200 32 GB cameras
2 Photron SA5 32 GB cameras
6 kHz acquisition rate

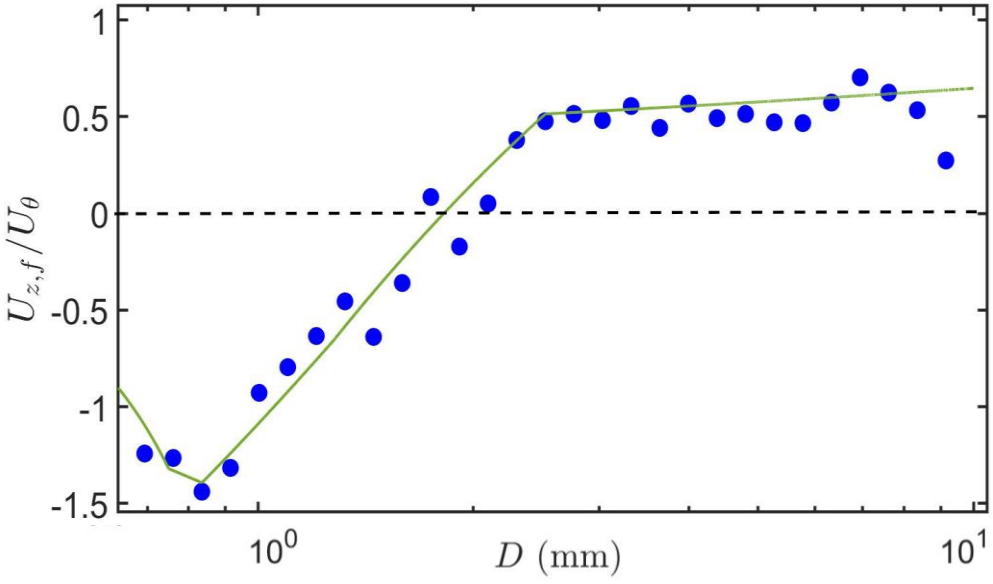
Bubble mean rise velocity plot

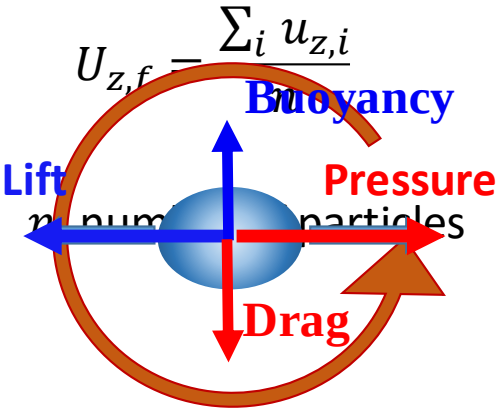


Bubble mean rise velocity plot









Bubble mean rise velocity plot

Thank you