Hinze scale bubble deformation and breakup in strong turbulence

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Johns Hopkins University

Fluid Transport

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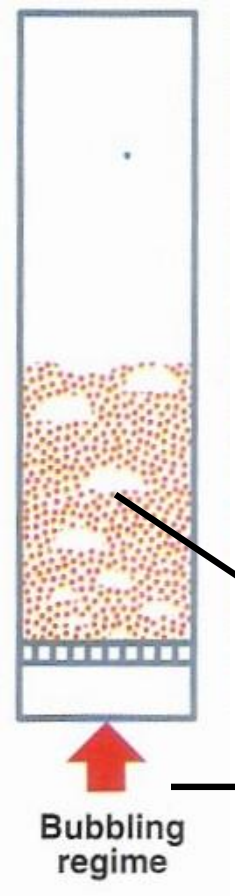
Motivation

Addressing the complex shapes in multiphase flows is challenging in both simulations and experiments

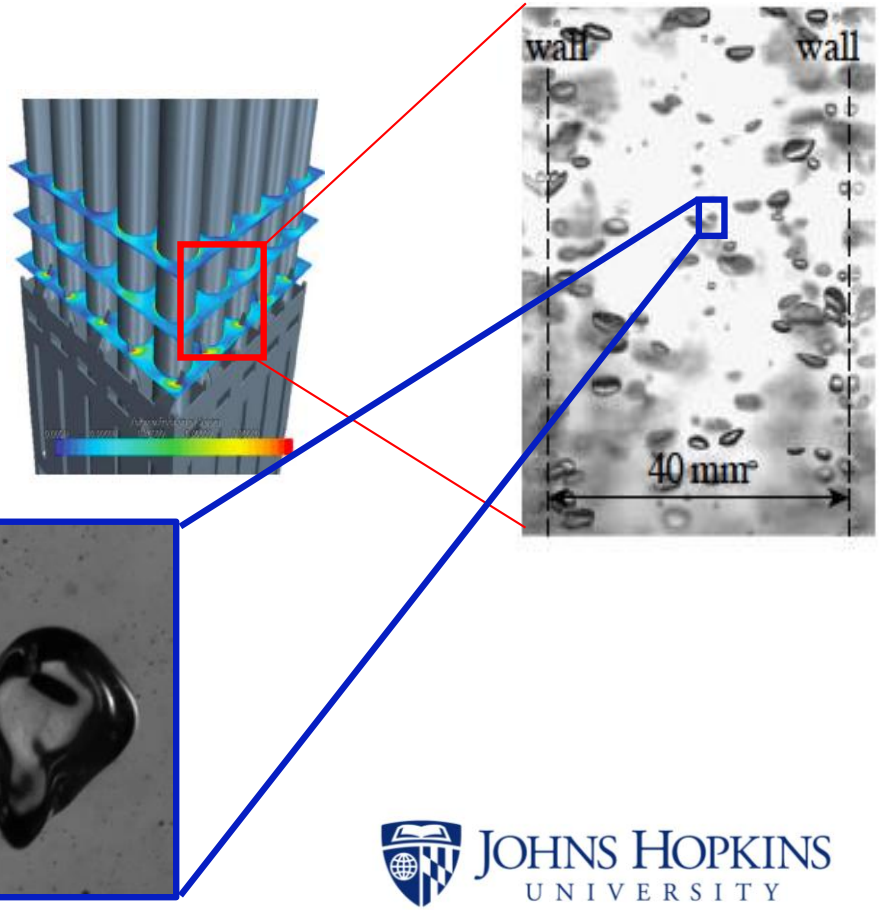


Fluidized bed reactor

Experimental challenges:

- **Measurement e.g. imaging**
- **Reconstruction**

Nuclear thermo-hydraulics



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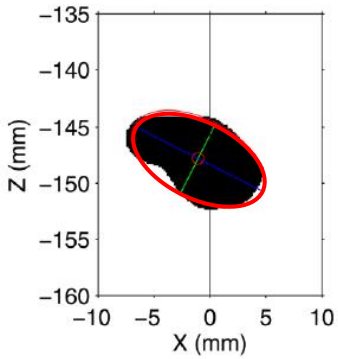
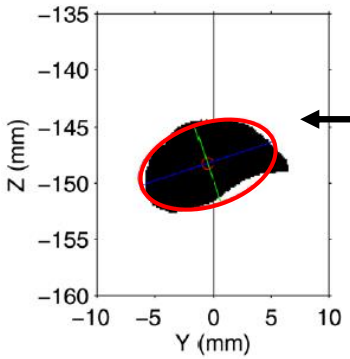
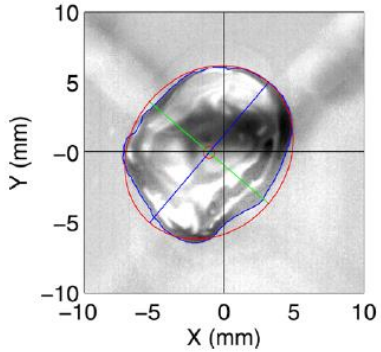
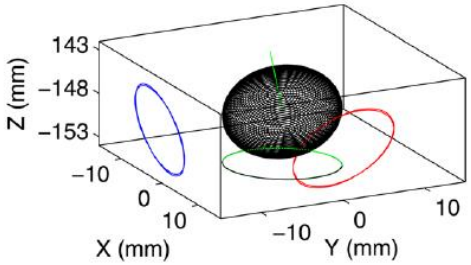
Motivation





Fitting ellipsoid to the 2D images of Bubbles.





- **Spherical assumption**
- **Rigid assumption**
- **Ellipsoid fitting**

Ravelet et. al. (2011)

shape → forces → Dynamics

Numerical simulations considering complex rigid shape [(Paschkewitz et. al. (2004), He et. al. (2017)] or deformable shapes [Lu and Tryggvasson (2008), Spandan et. al. (2017)] are very rare

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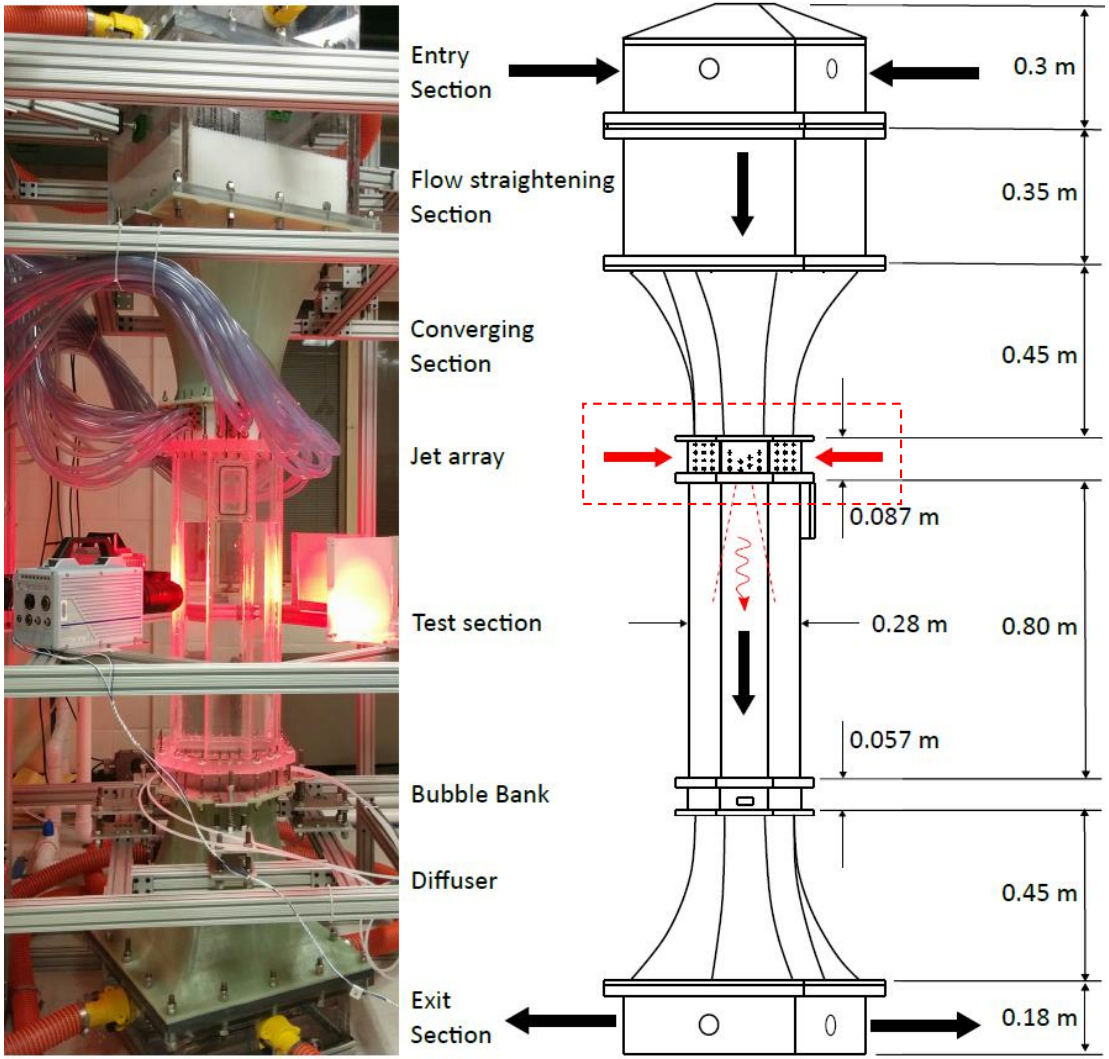
V-ONSET(Vertical Octagonal Non-corrosive Stirred Energetic Turbulence)



- Opposing mean flow
- High energy dissipation rate

Masuk et. el. (RSI, 2019)

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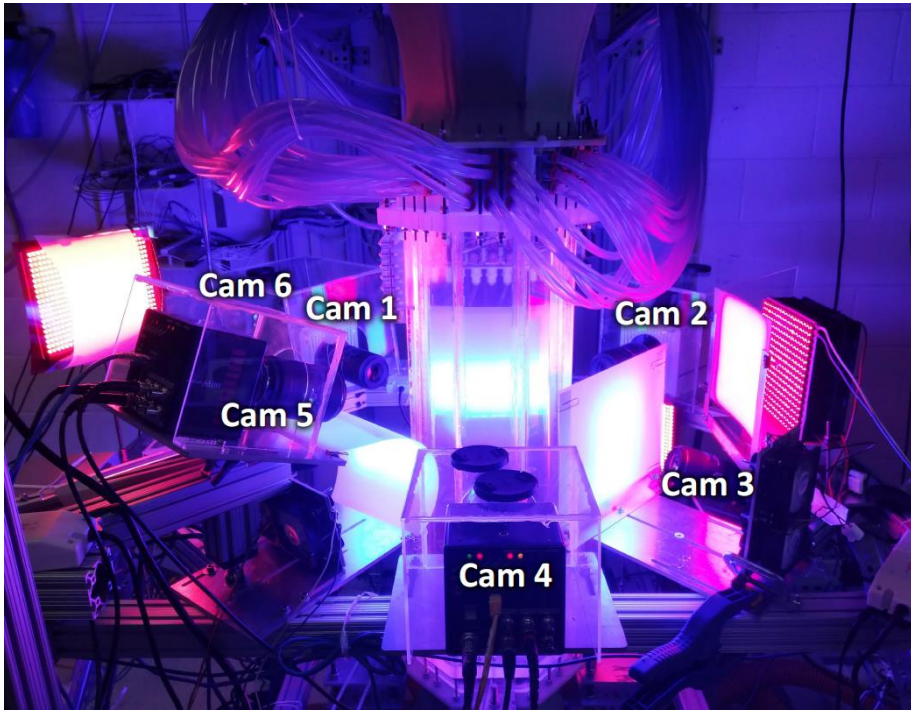
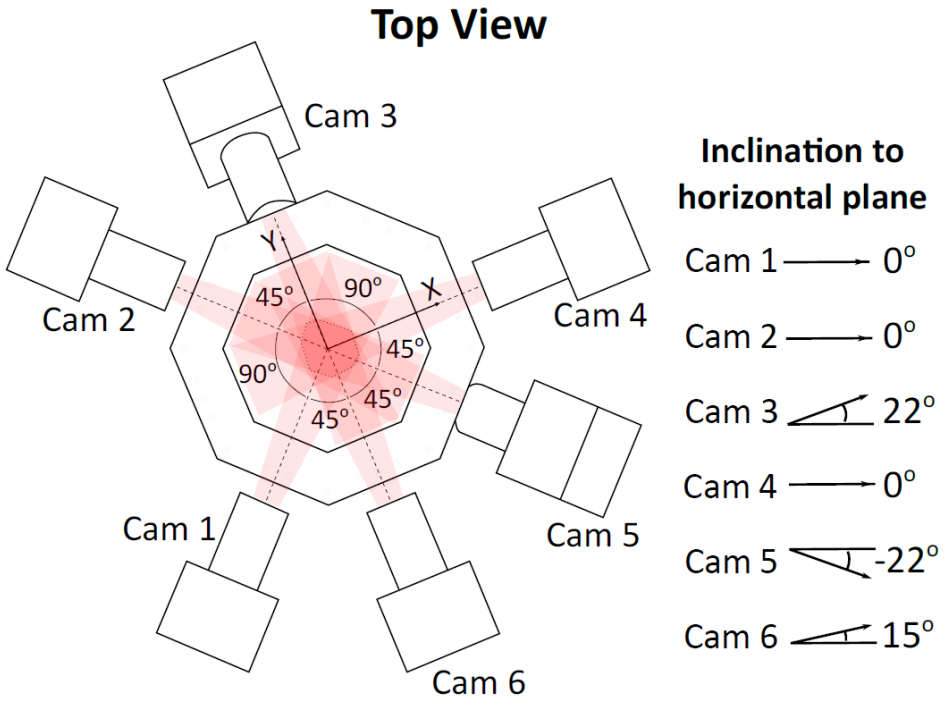
Imaging of the test section with 6 high speed cameras





4 Photron AX200
2 Photron SA Series
Upto 6400 fps

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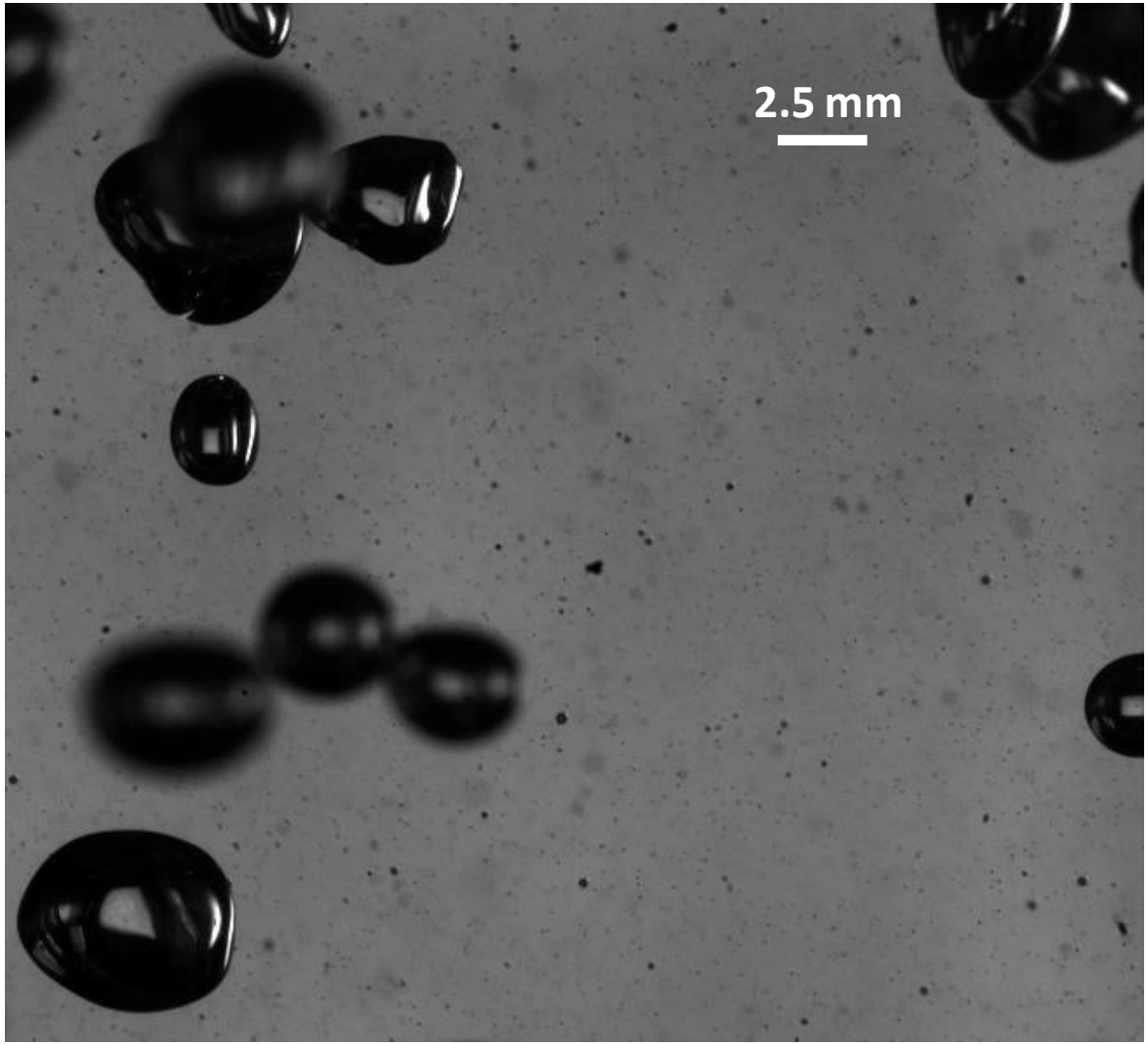
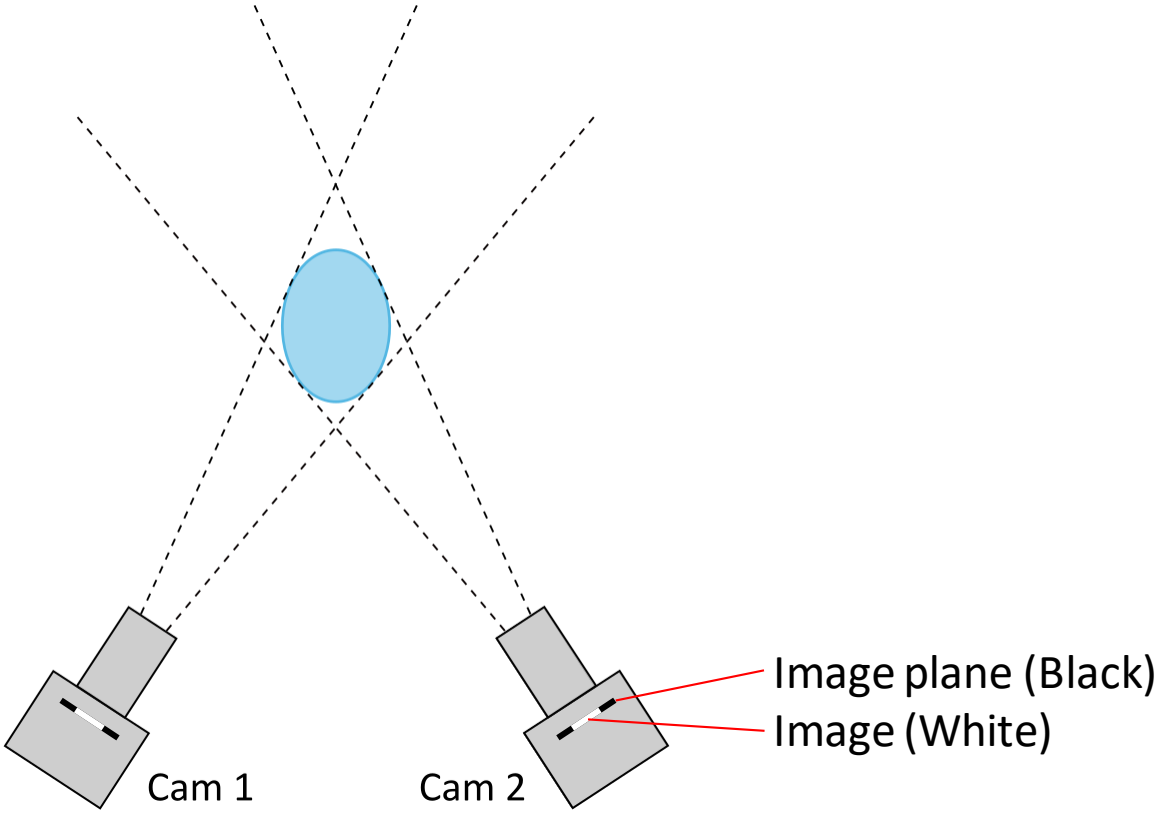
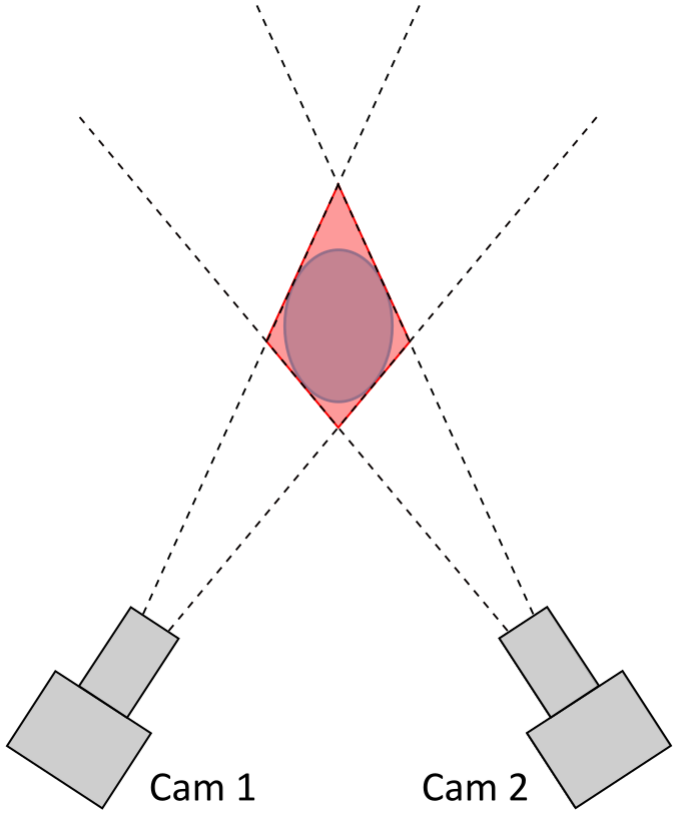


Raw images of air bubbles in turbulent water imaged at 4000 fps

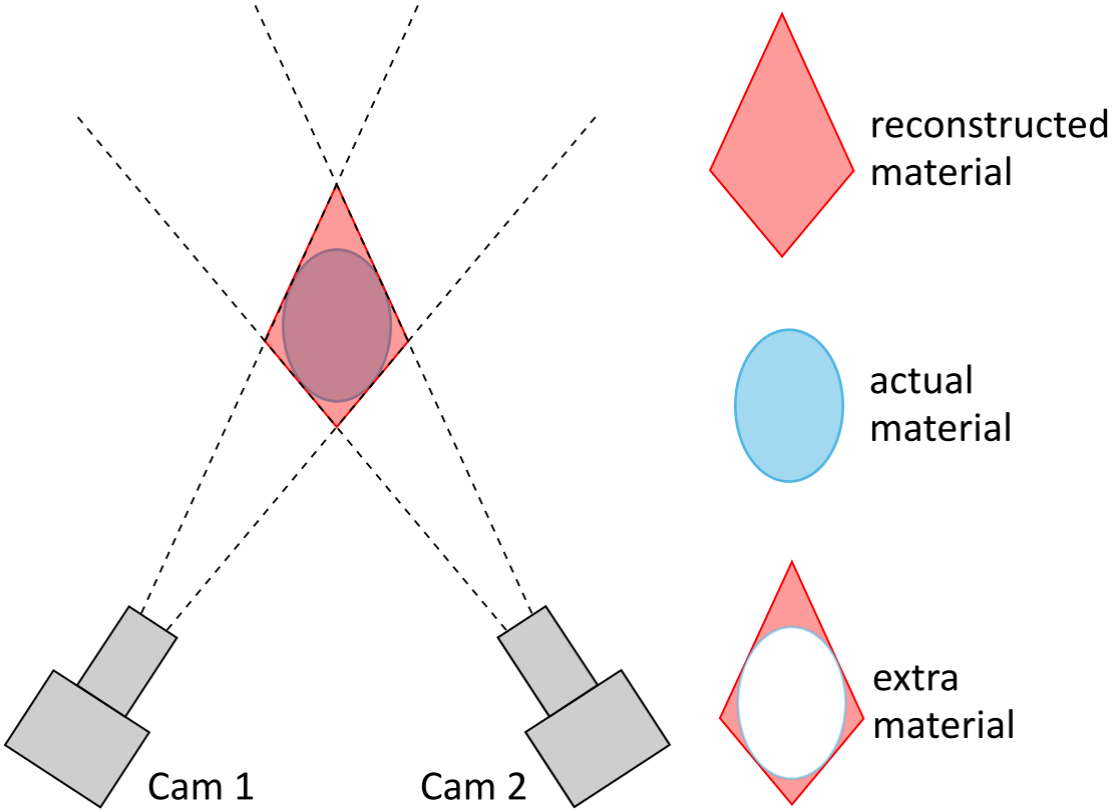
Visual hull reconstruction



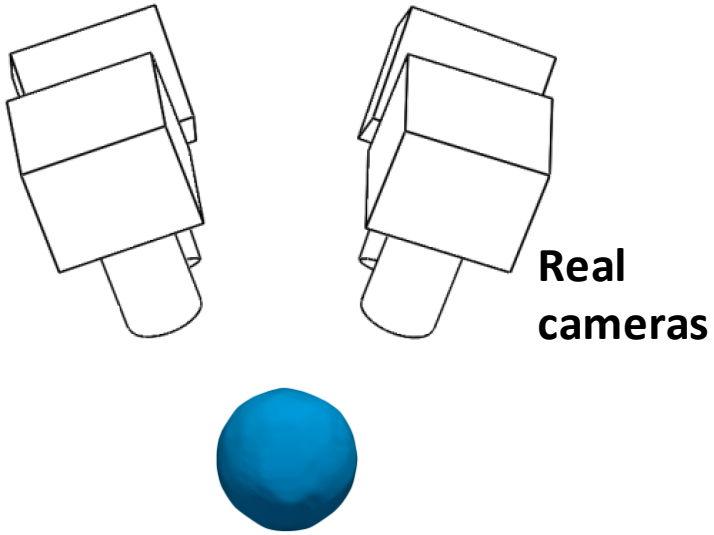
Visual hull reconstruction



Visual hull reconstruction

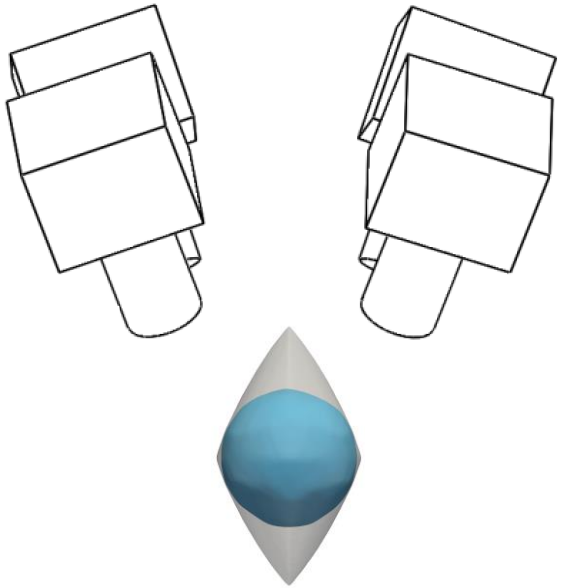


Virtual Camera Method



4 real cameras viewing an spherical object from one side

Virtual Camera Method



Visual hull shown as gray envelope

Virtual Camera Method

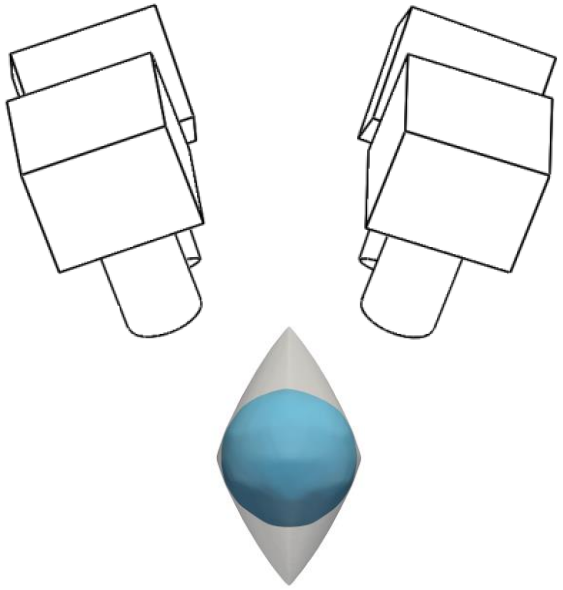
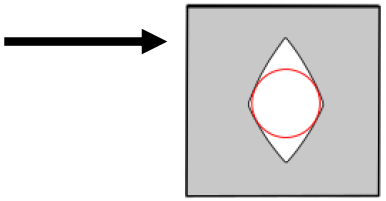


Image plane of the first virtual camera



Optimize the angle between a virtual camera and other existing cameras

Virtual Camera Method

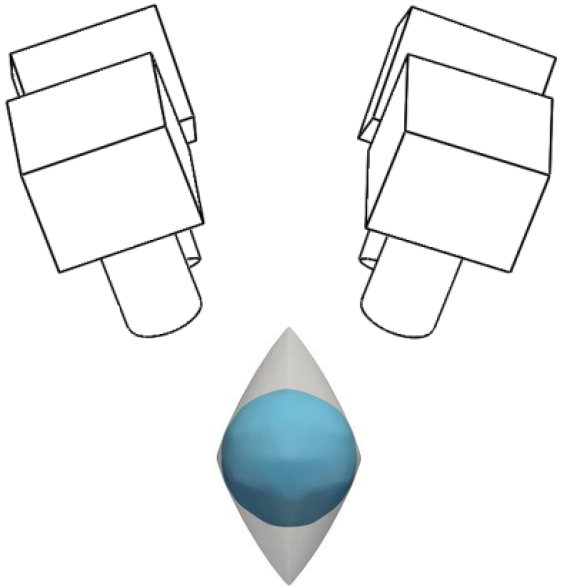
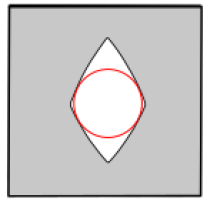
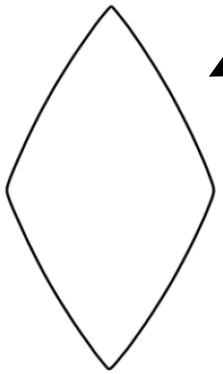


Image plane of the first virtual camera





outline

Virtual Camera Method

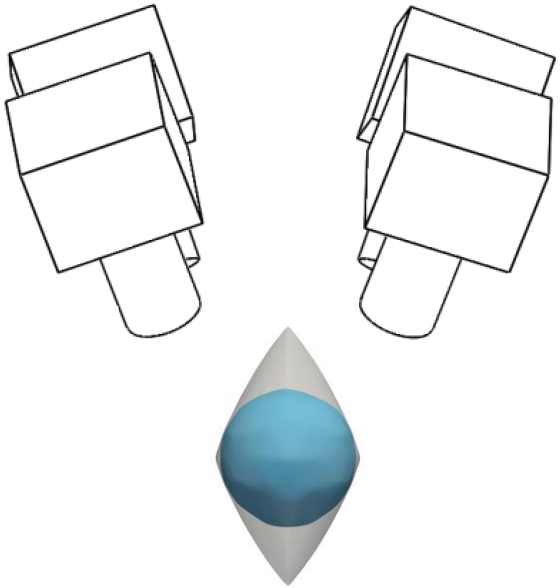
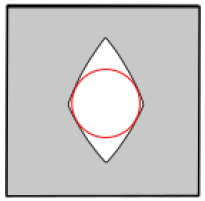
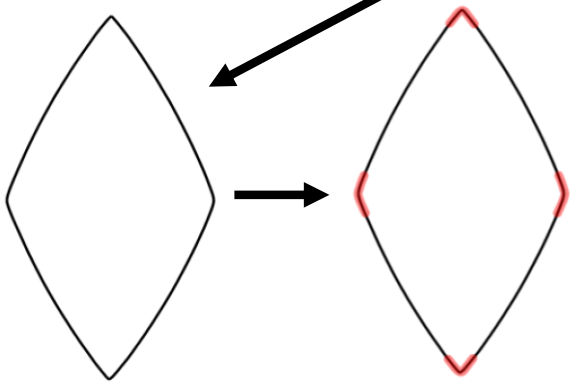


Image plane of the first virtual camera





outline

High curvature

Virtual Camera Method

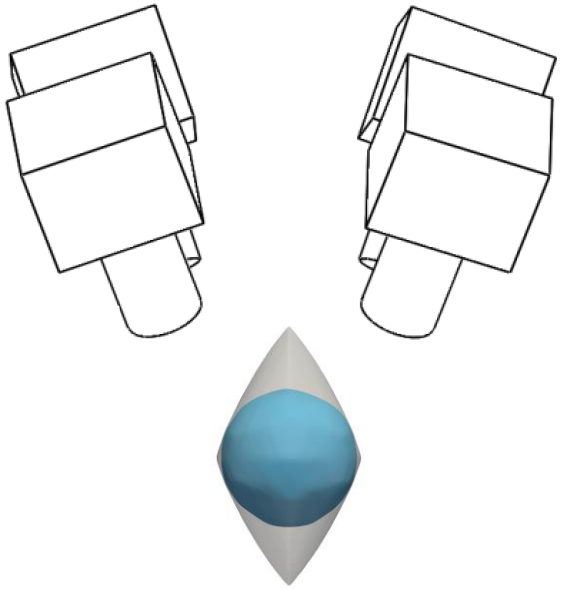
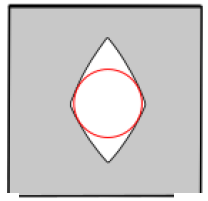
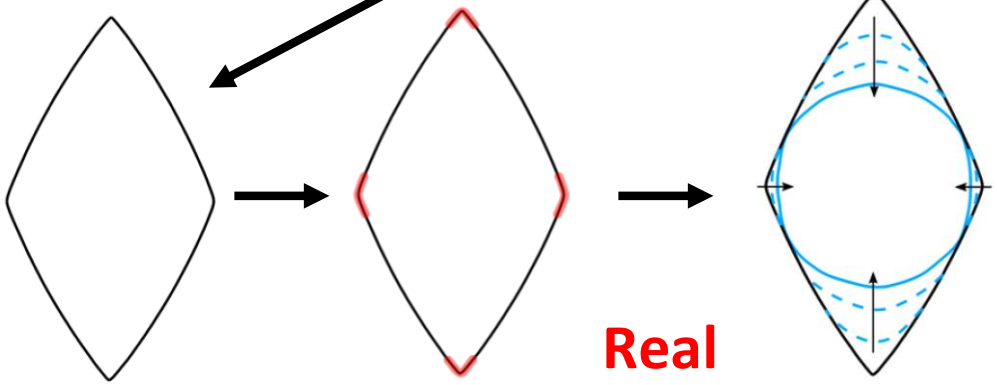


Image plane of the first virtual camera





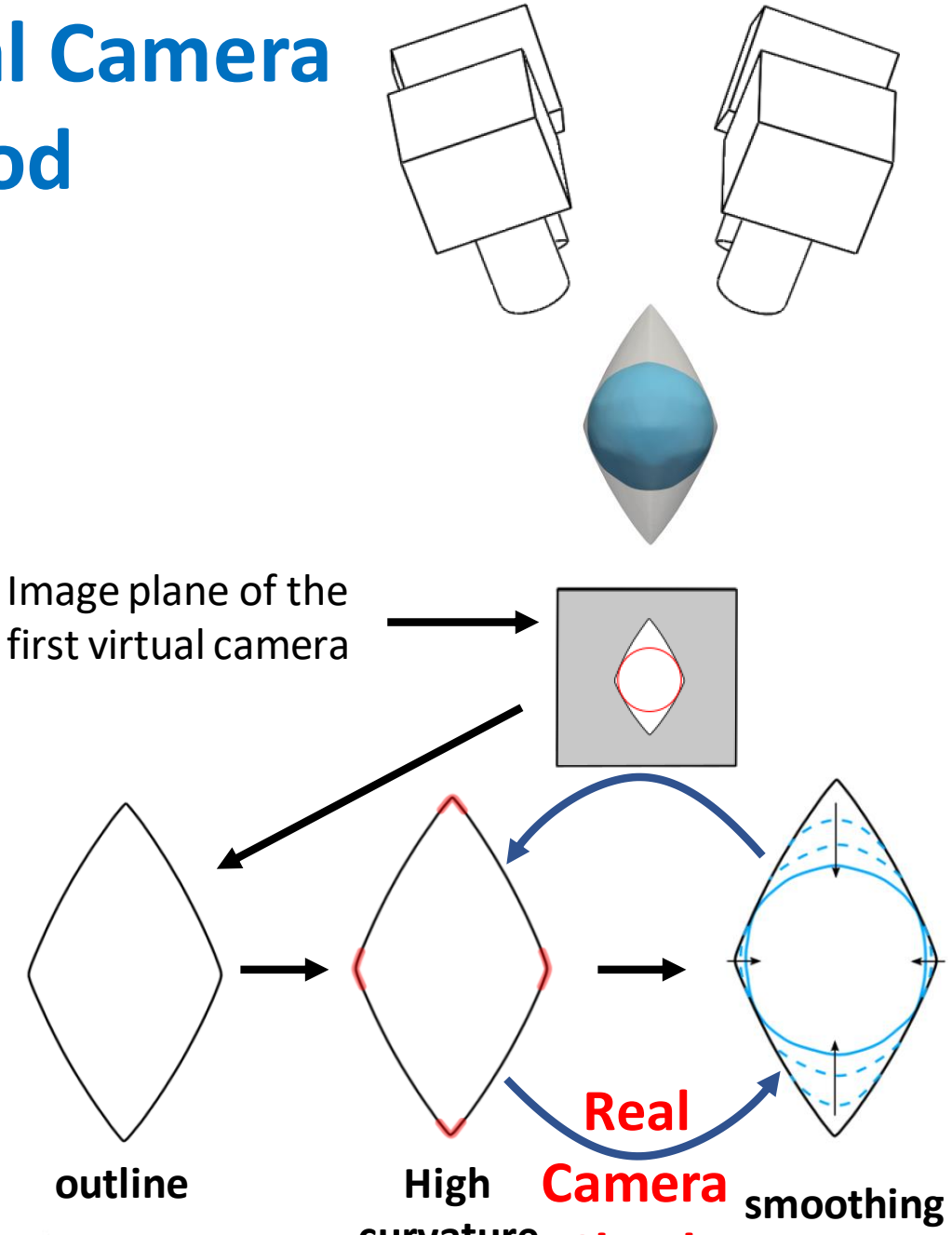
outline

High curvature

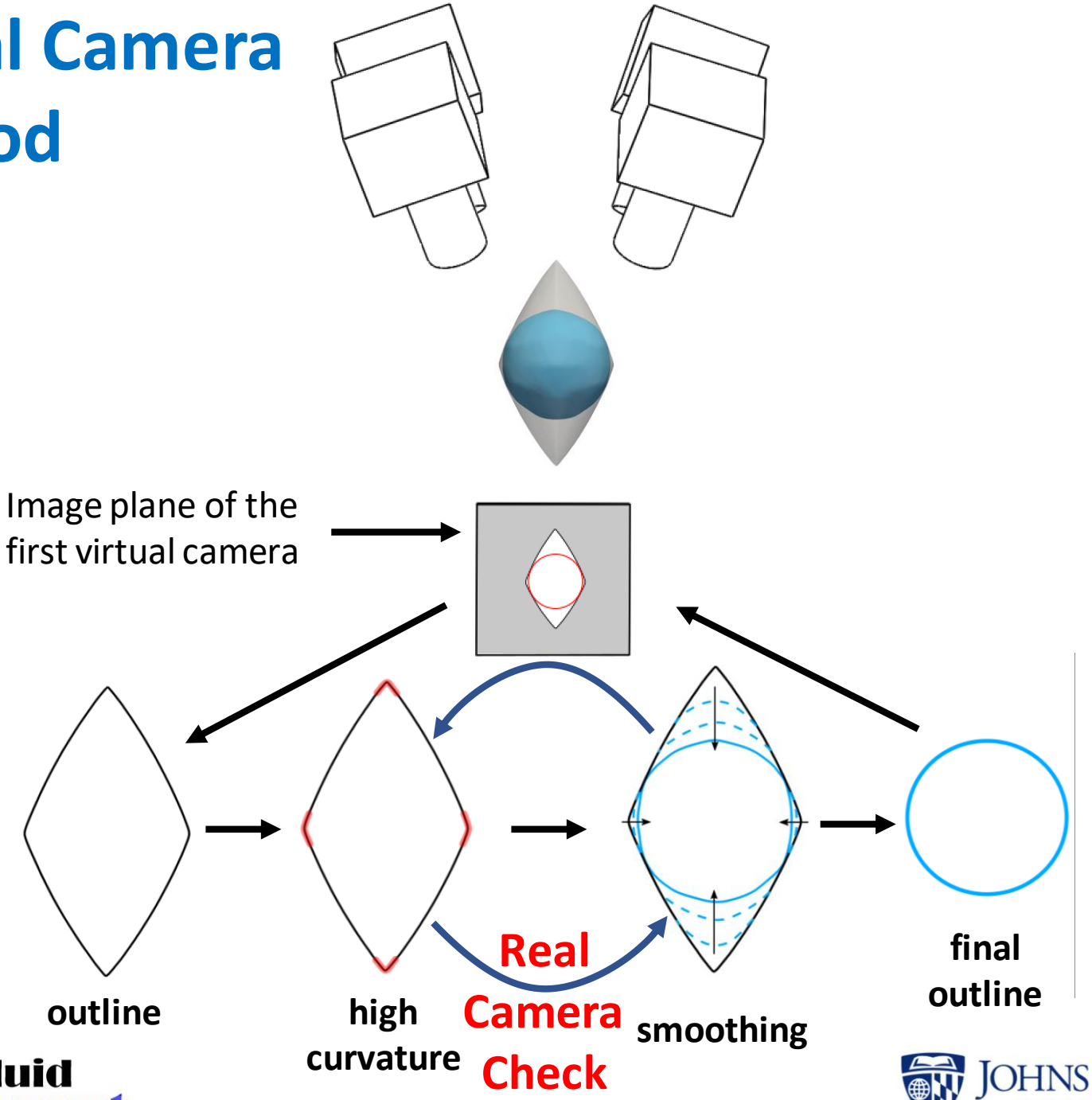
Real Camera Check

smoothing

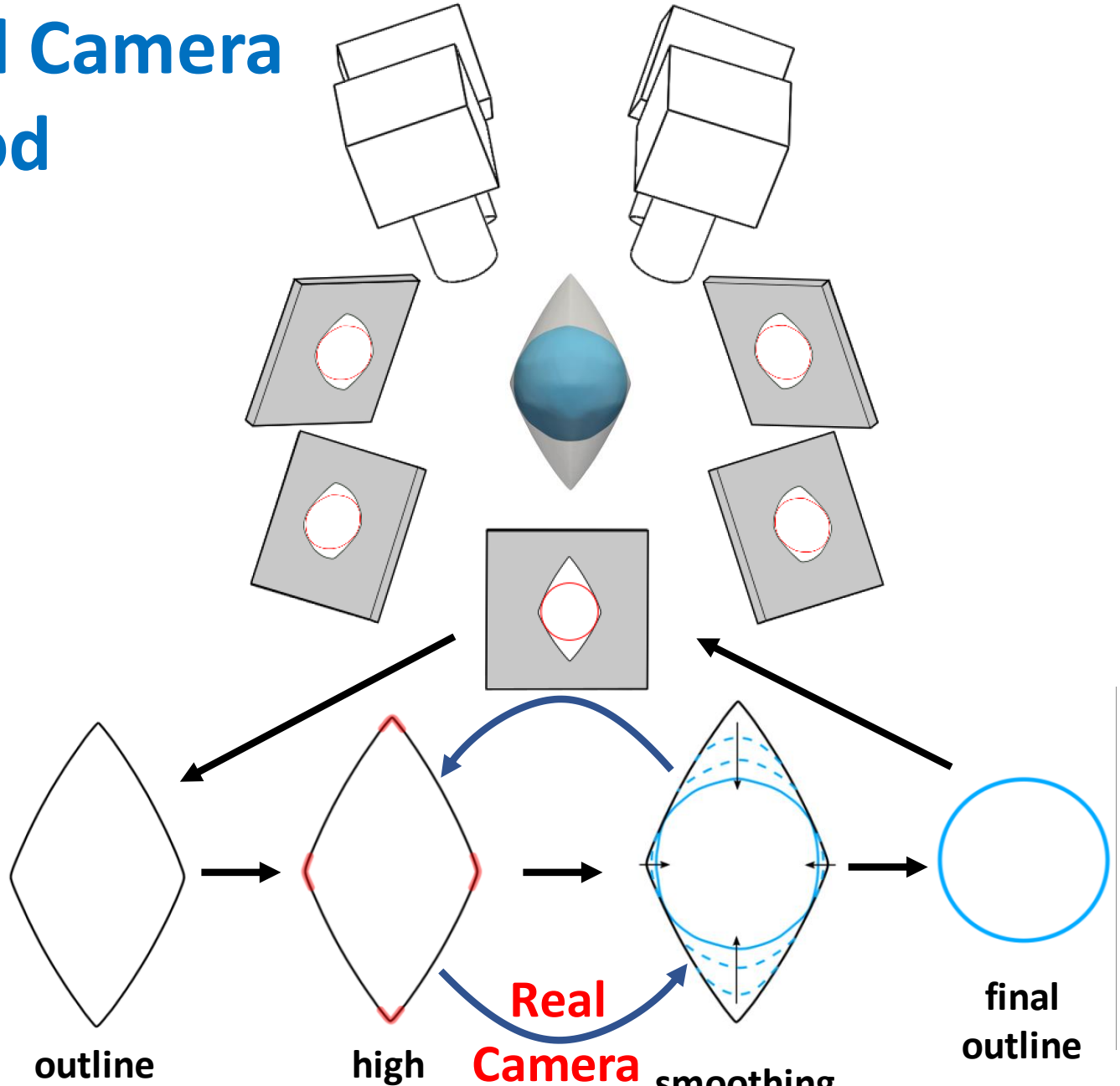
Virtual Camera Method



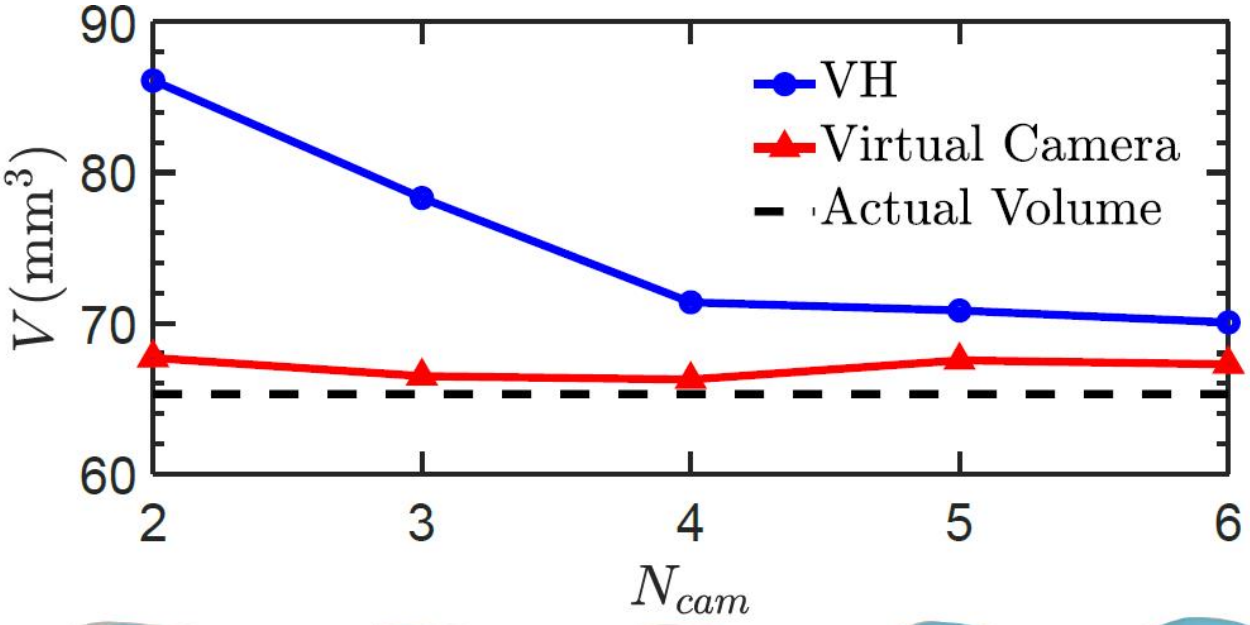
Virtual Camera Method

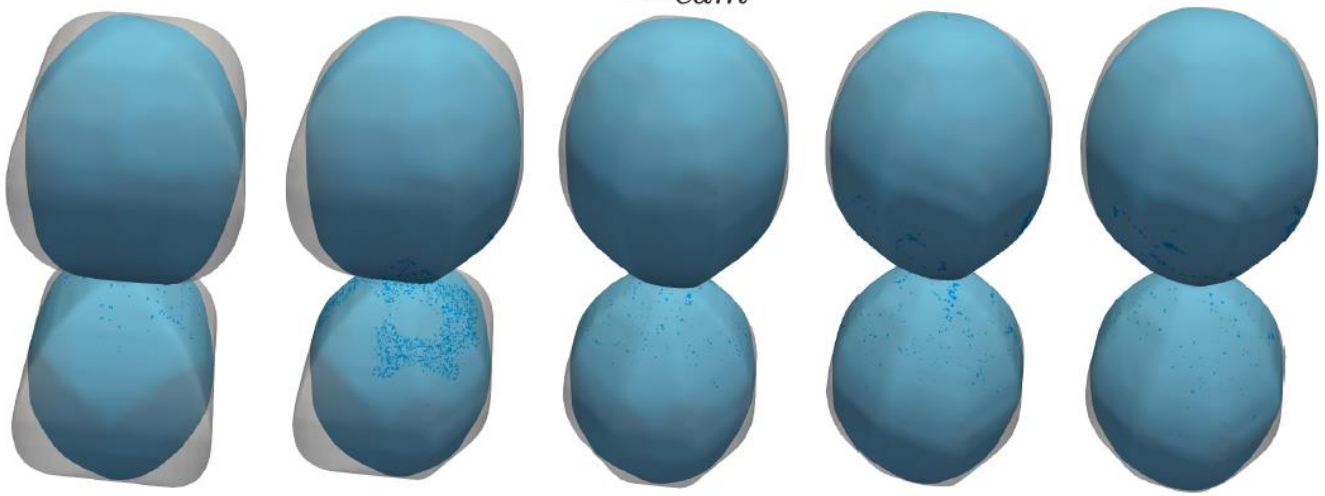


Virtual Camera Method

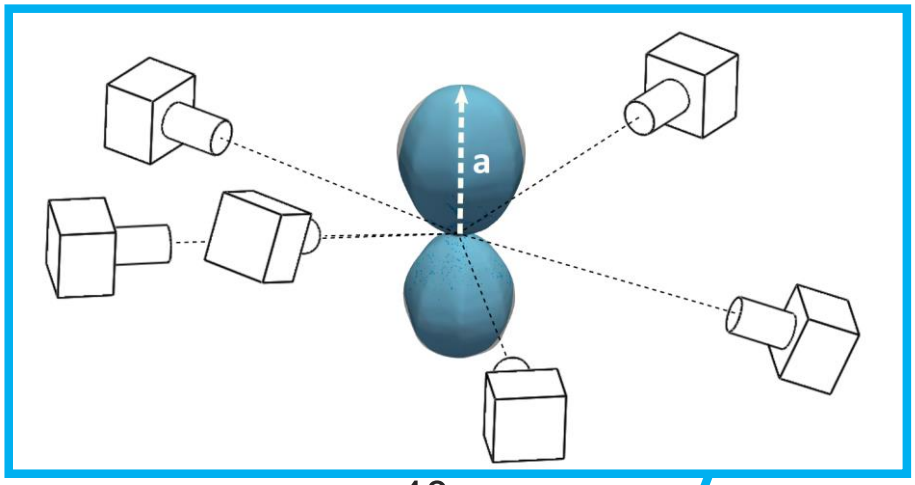


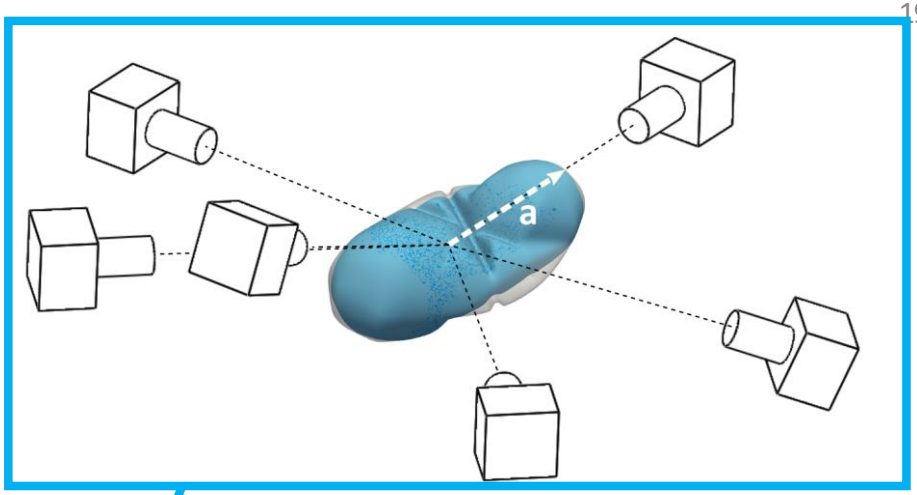
Synthetic Dumbbell Reconstruction

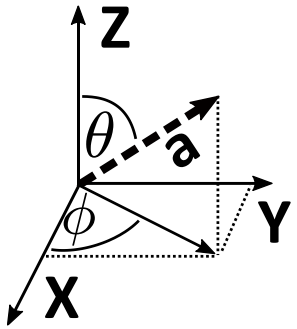


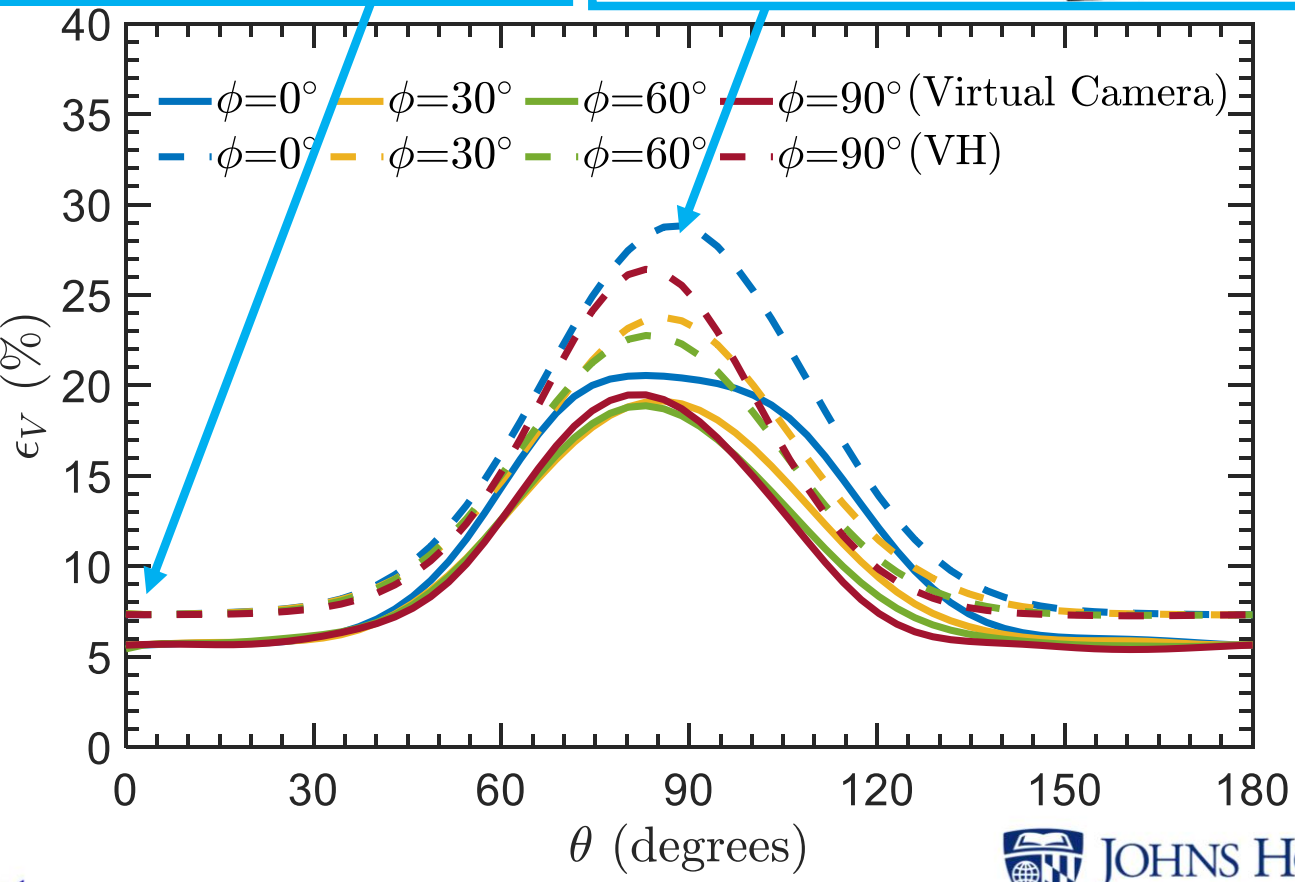


breakup scenario









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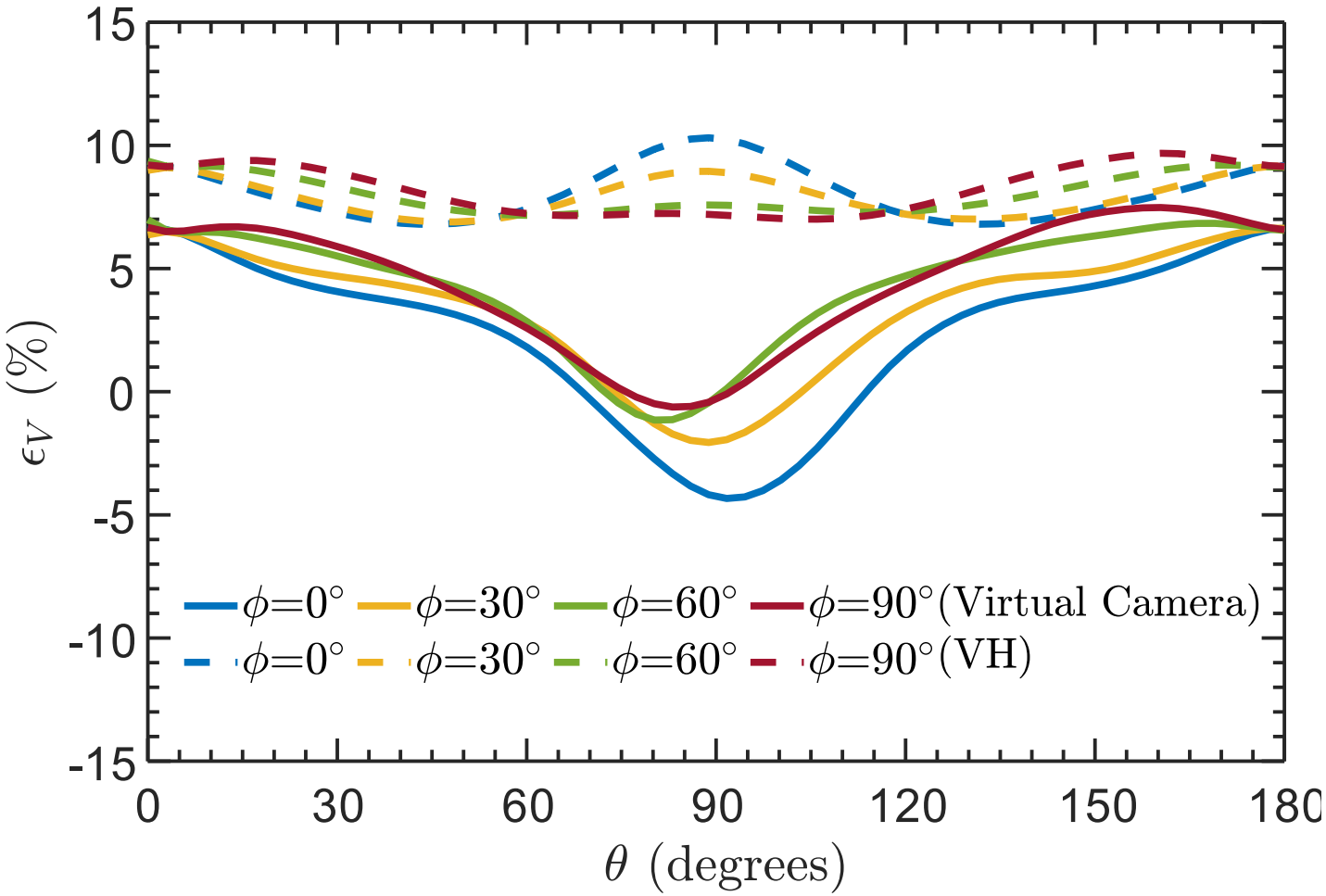
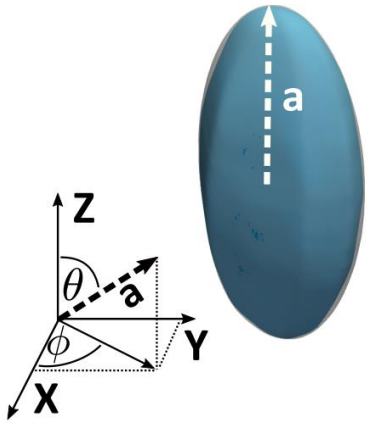
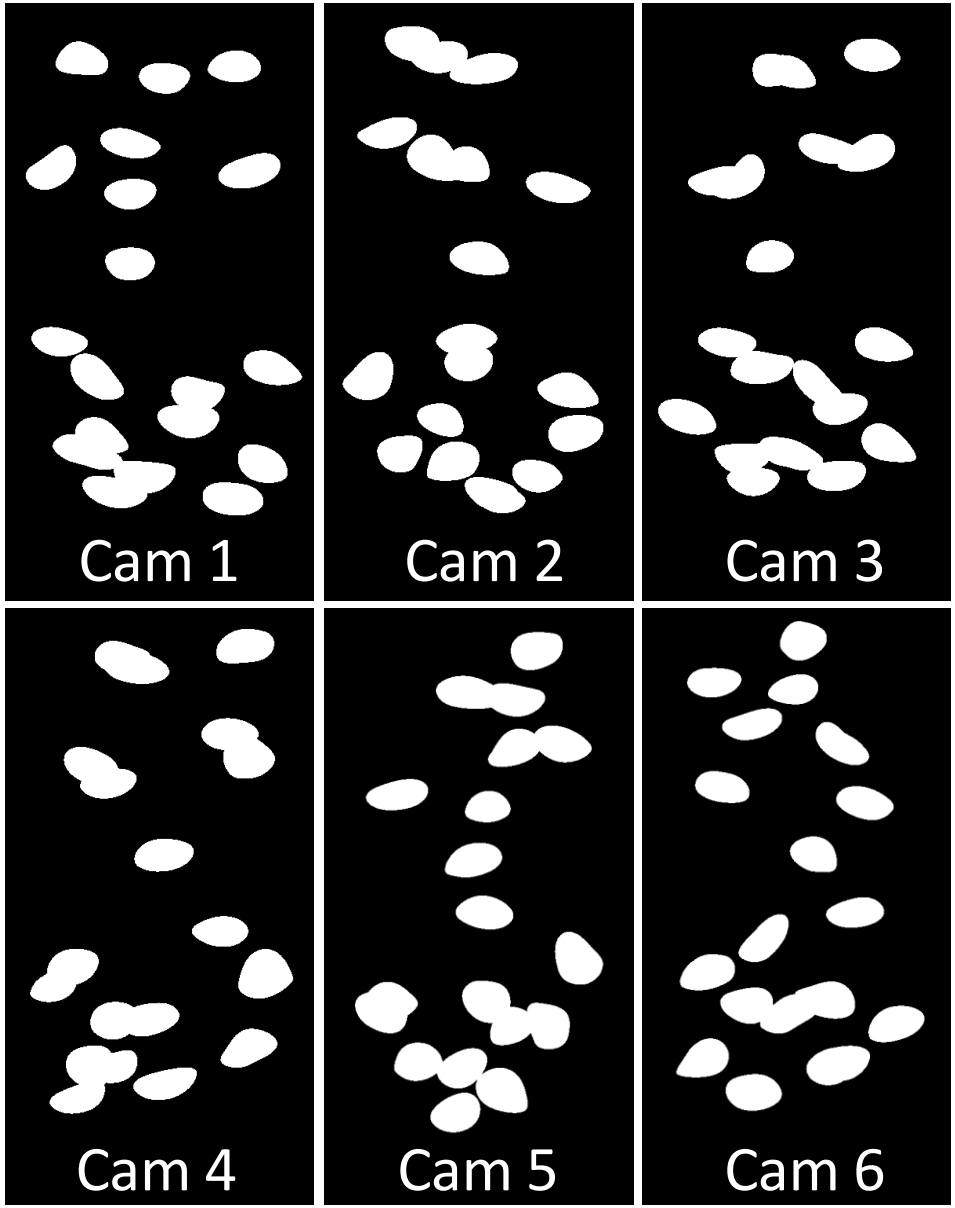




$\boldsymbol{\alpha = 3}$

DNS data reconstruction

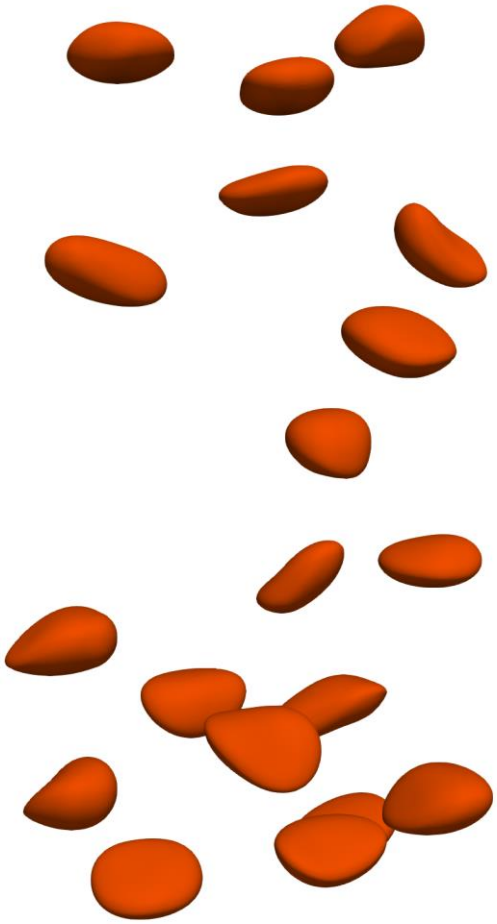
Synthetic images from DNS dataset



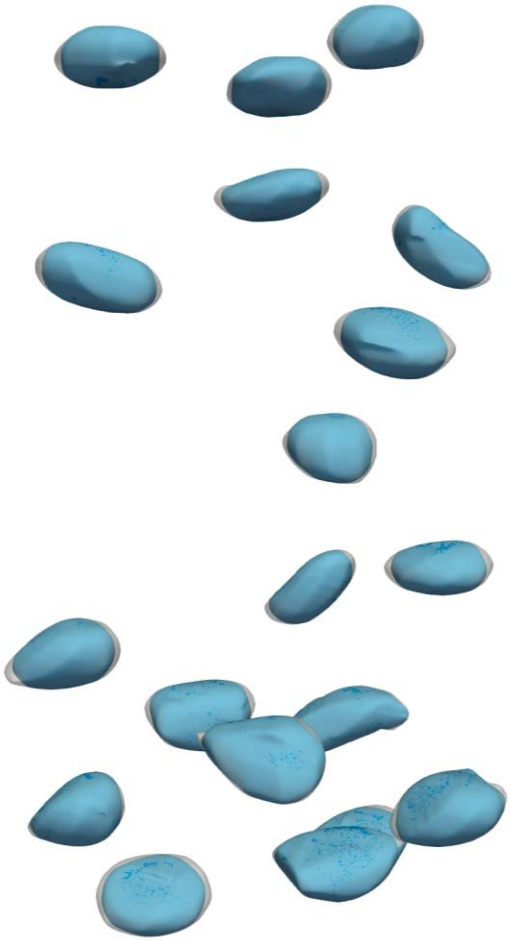
No need for 2D Segmentation!

Lu and Tryggvasson (2008)

DNS data reconstruction

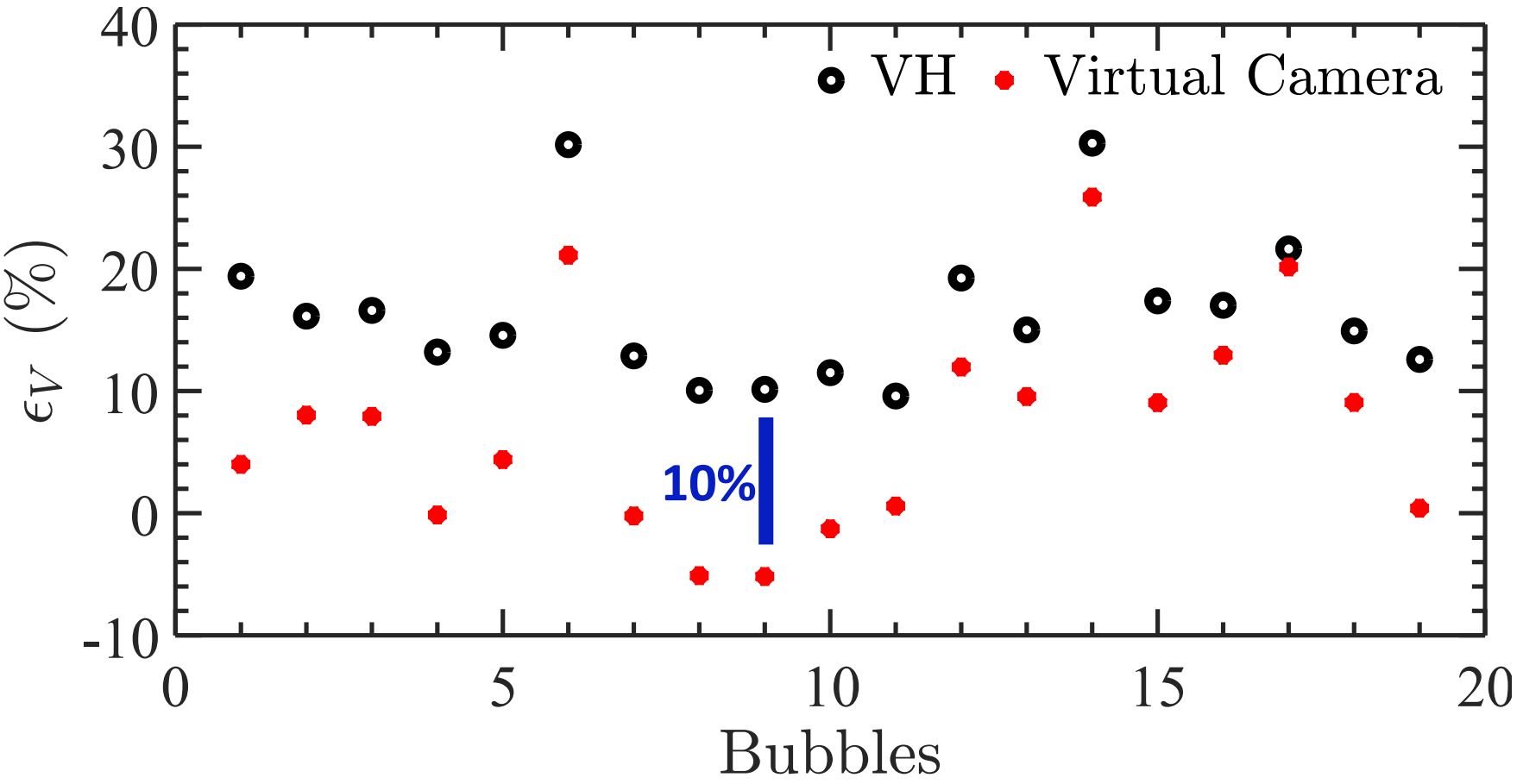


DNS

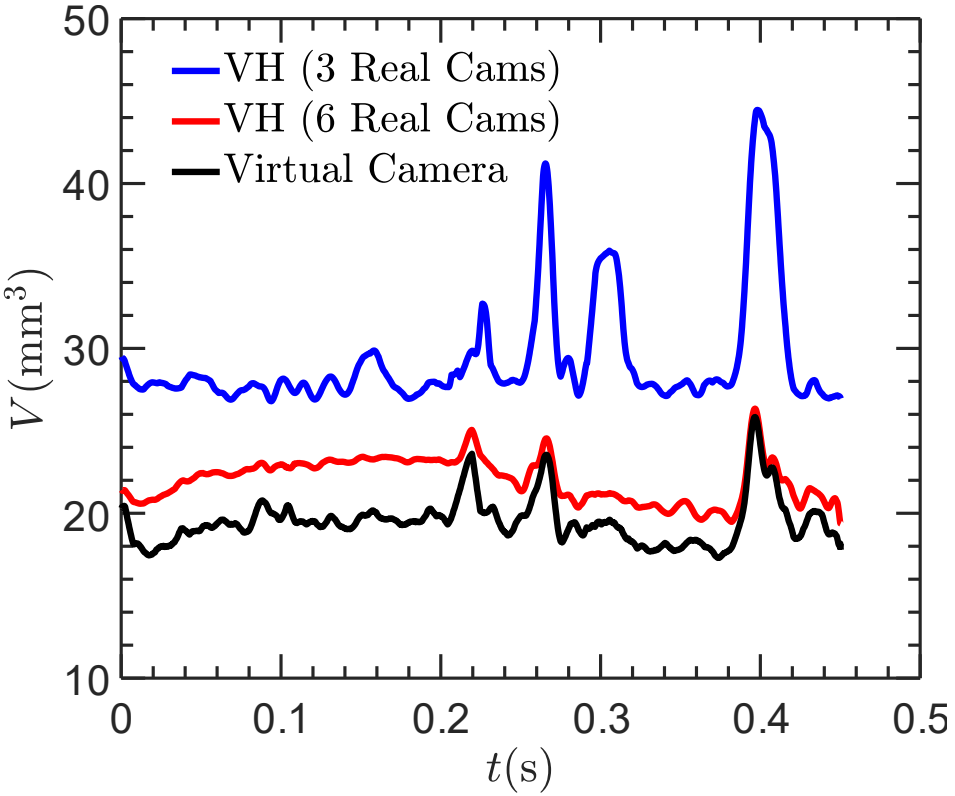


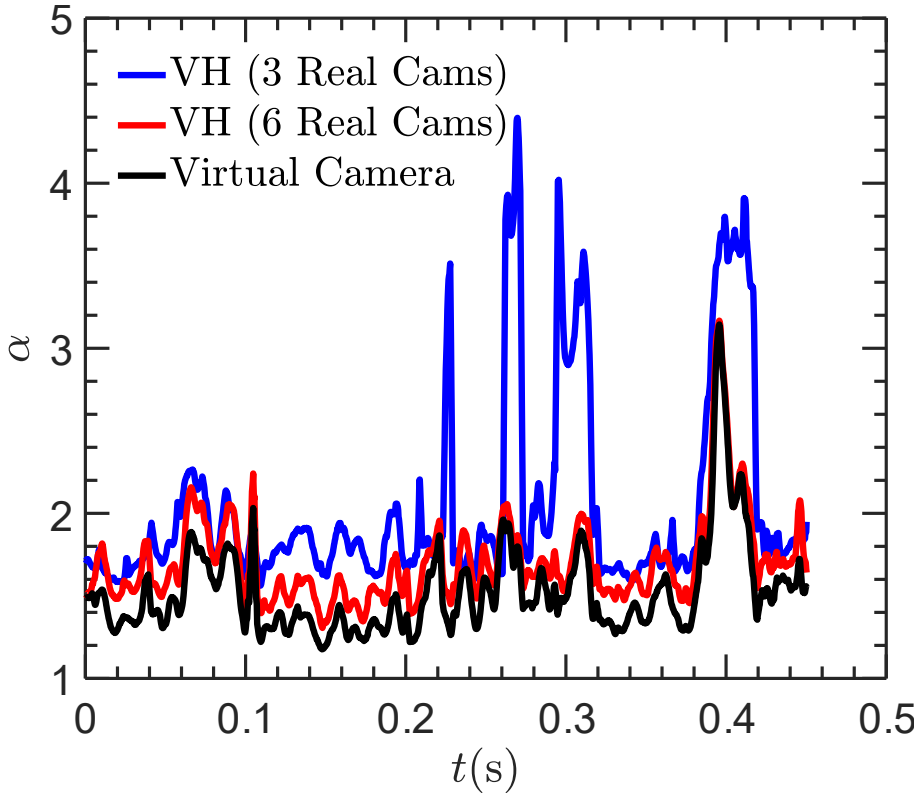
Virtual Camera

DNS data reconstruction



Experimental Results





A robust virtual-camera 3D shape reconstruction of deforming bubbles/droplets with additional physical constraints (IJMF, under review)

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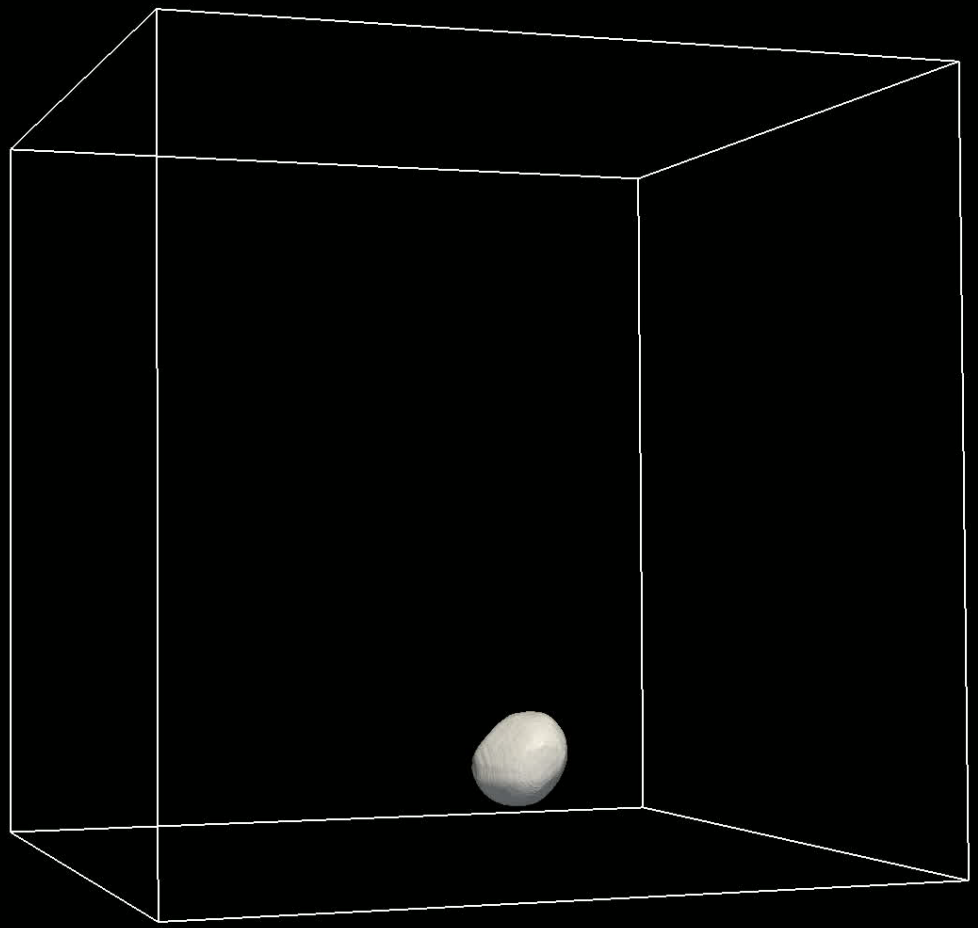
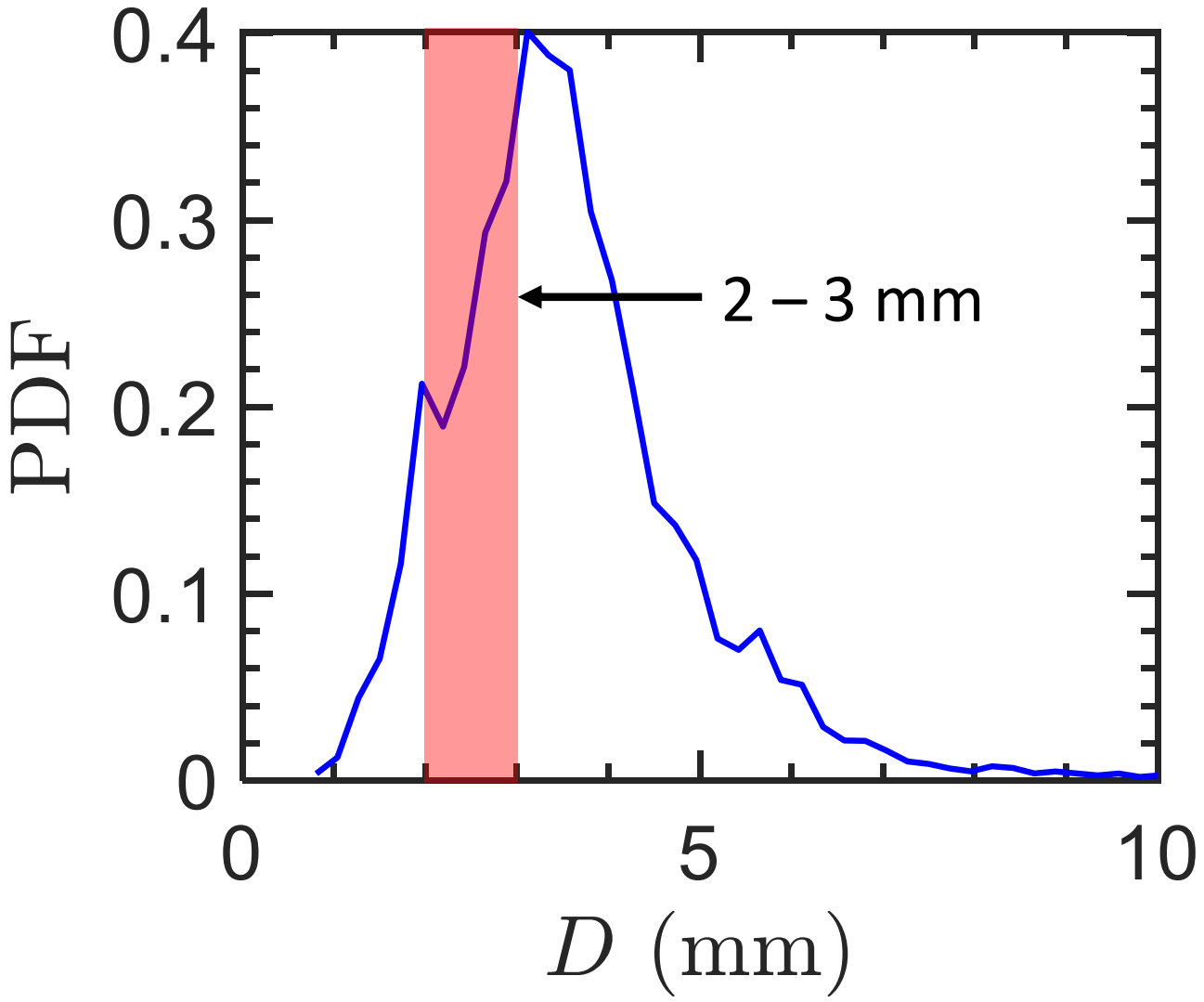


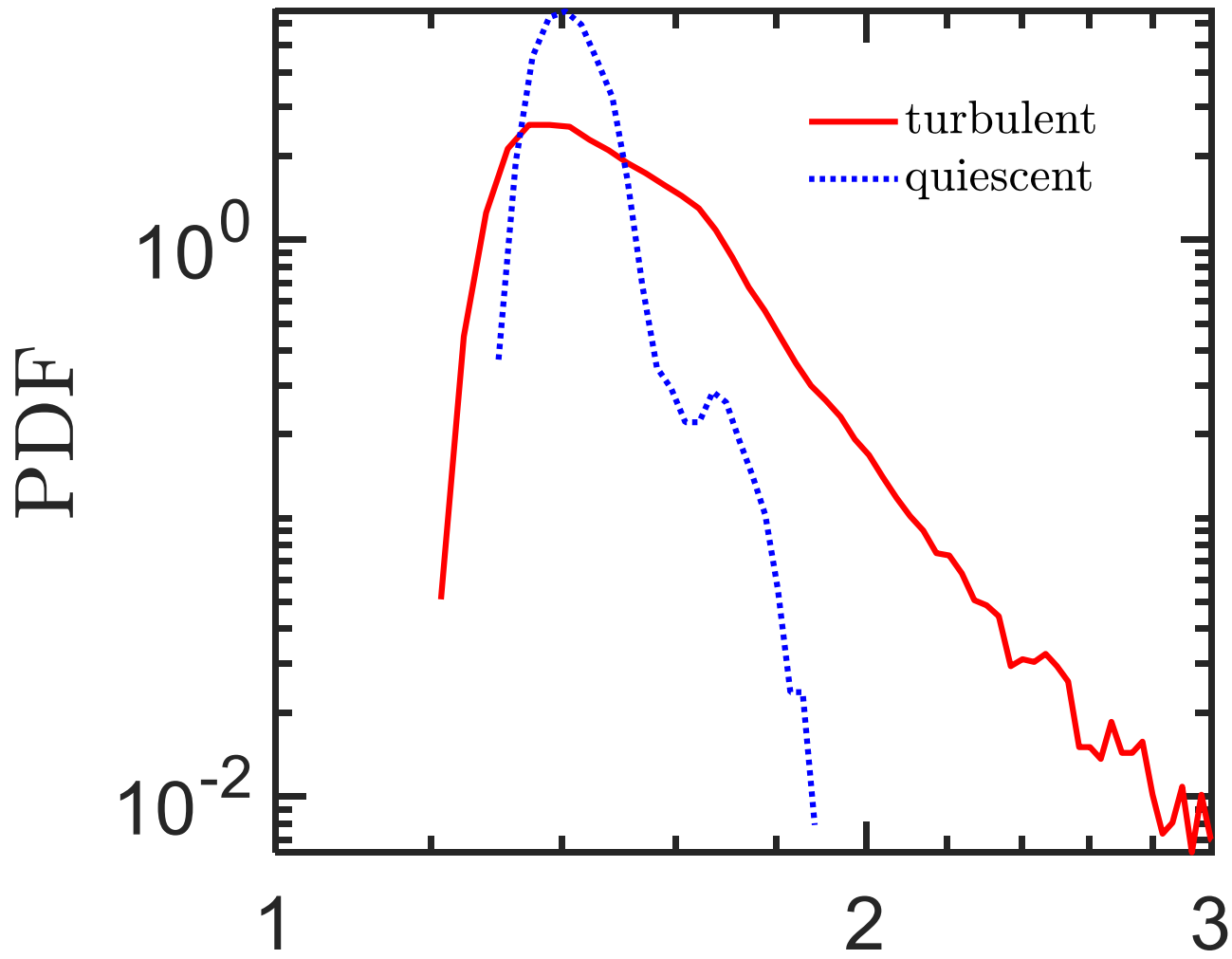
Time: 0.00 ms

Bubble size distribution

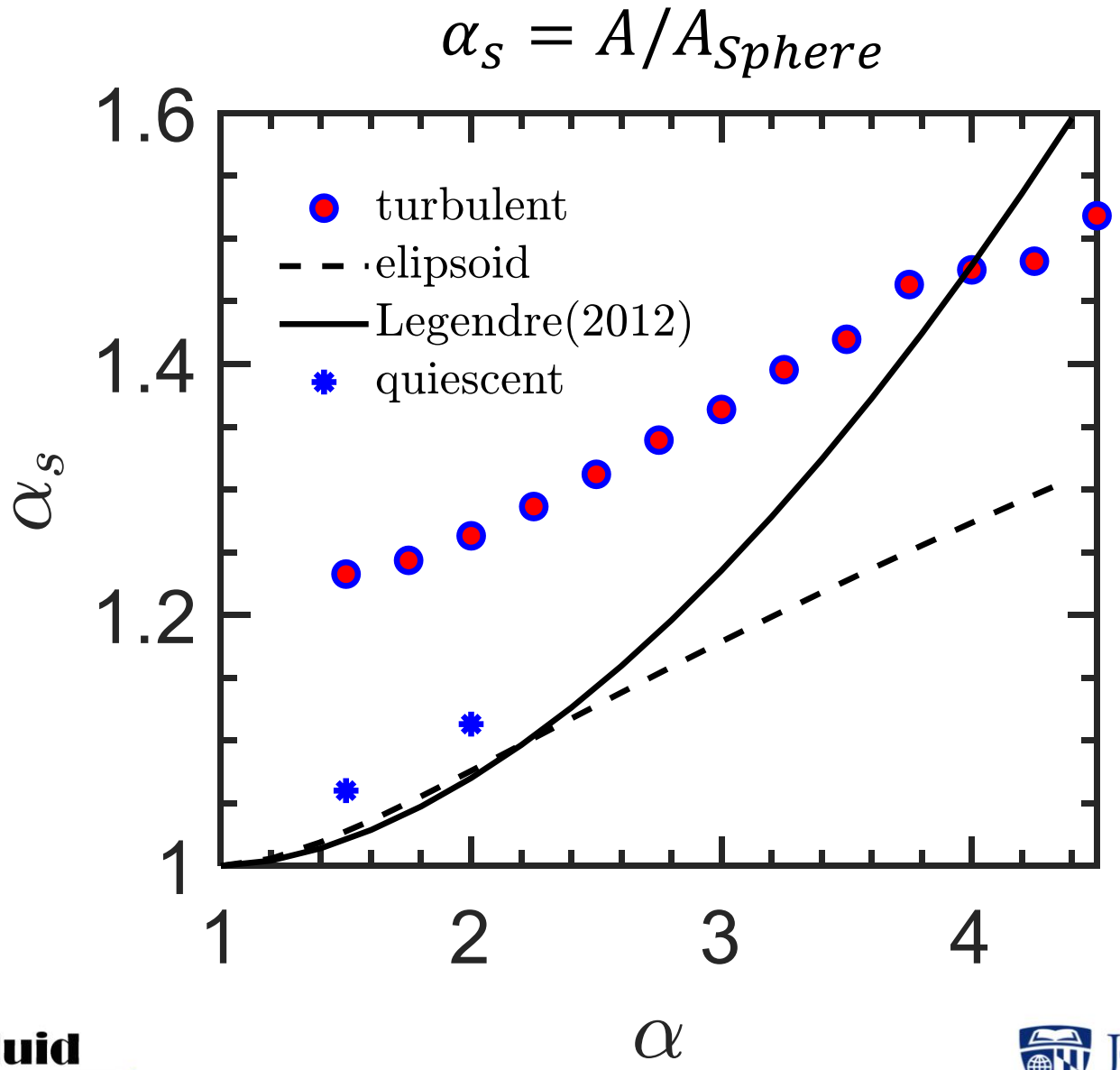


Aspect ratio PDF

$$\alpha = r_{max}/r_{min}$$

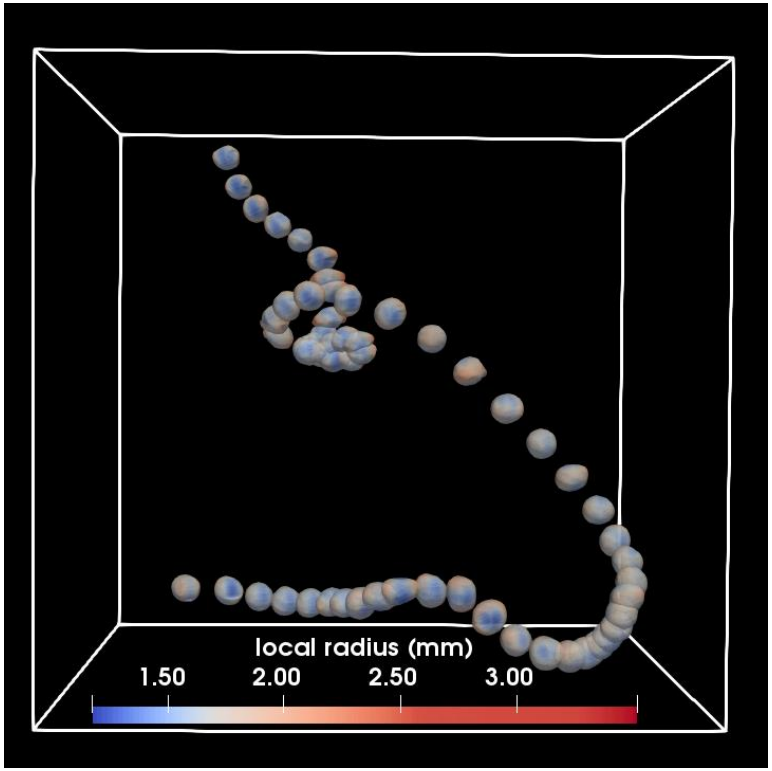


Surface area increases due to non-affine deformation



Conclusion

- A new **Virtual Camera** method was developed for 3D shape reconstruction of bubbles/droplets in turbulence.
- No need for 2D segmentation
- The methods helps to reconstruct non-affine deformation in turbulence.
- In strong turbulence bubbles deform significantly more than that represented by an ellipsoid



Award Nos. 1705246
CAREER-1653389

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