Foam Scatter
Grenoble, 2022

3D characterisation of liquid foam flow

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Swedish Research Council

LUND UNIVERSITY

UNIVERSITÉ CÔTE D'AZUR

UGA Université Grenoble Alpes

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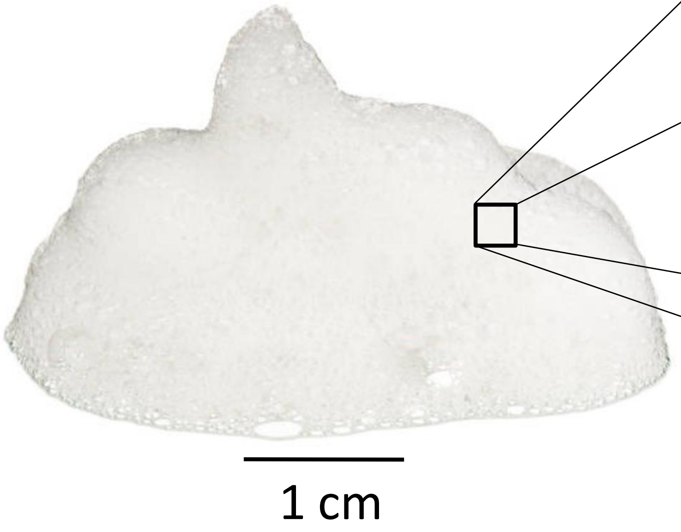
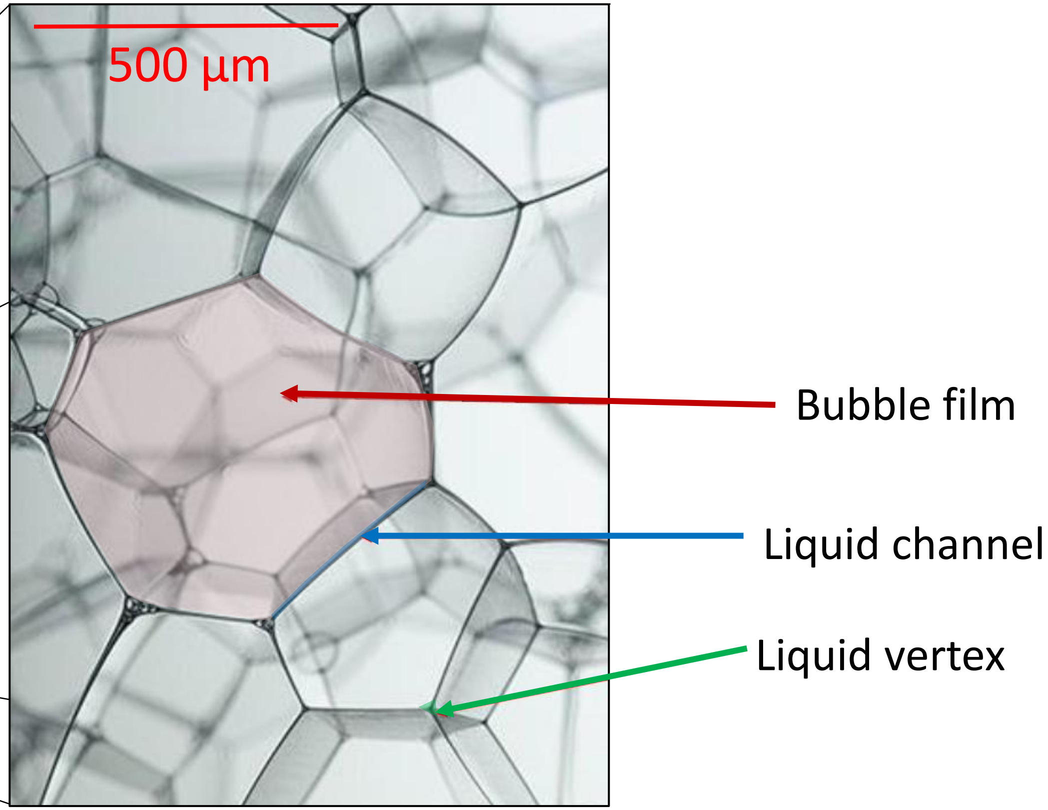
MAX IV

Liquid foam – Structure

Liquid foam
= dispersion of gas bubbles into a continuous liquid phase
= interfaces stabilised by surfactants



Credit: istockphoto.com, Nov 2021



Credit: Sascha Heitkam, "Bubble, Foam, Froth" course, Technische Universität Dresden, 2020

Multiscale structure
soap film **(nano/micro)** – bubbles **(meso)** – foam **(macro)**

Liquid foam – Applications

Everyday-life products

Cosmetic

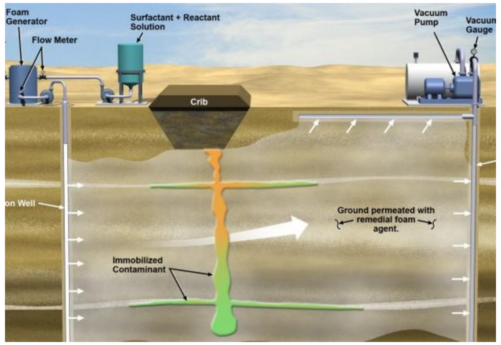
Tetra Images/Getty Images

Food science

Unsplash

Larger industrial applications

Soil remediation



Pacific Northwest National Laboratory, 2019

Firefighting

Shutterstock

General objective of our collaboration

Characterising experimentally and understanding the **deformations** and **interactions** of bubbles inside a **3D flowing liquid foam**

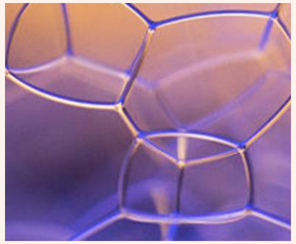
a long-standing collaborative effort!

Main technical challenges

3D imaging → Foam opacity

Spatial resolution → Foam structure

Bubble film < µm
Liquid channel **~ 3-50 µm**



Foam stability → Ageing

Stable for at least **1 min**

Solution

Fast x-ray micro-tomography, PSI synchrotron

Credit: https://www.psi.ch/en/sls/about-sls

Use of **fast x-ray micro-tomography** for **3D imaging of liquid foam flowing** through a constriction

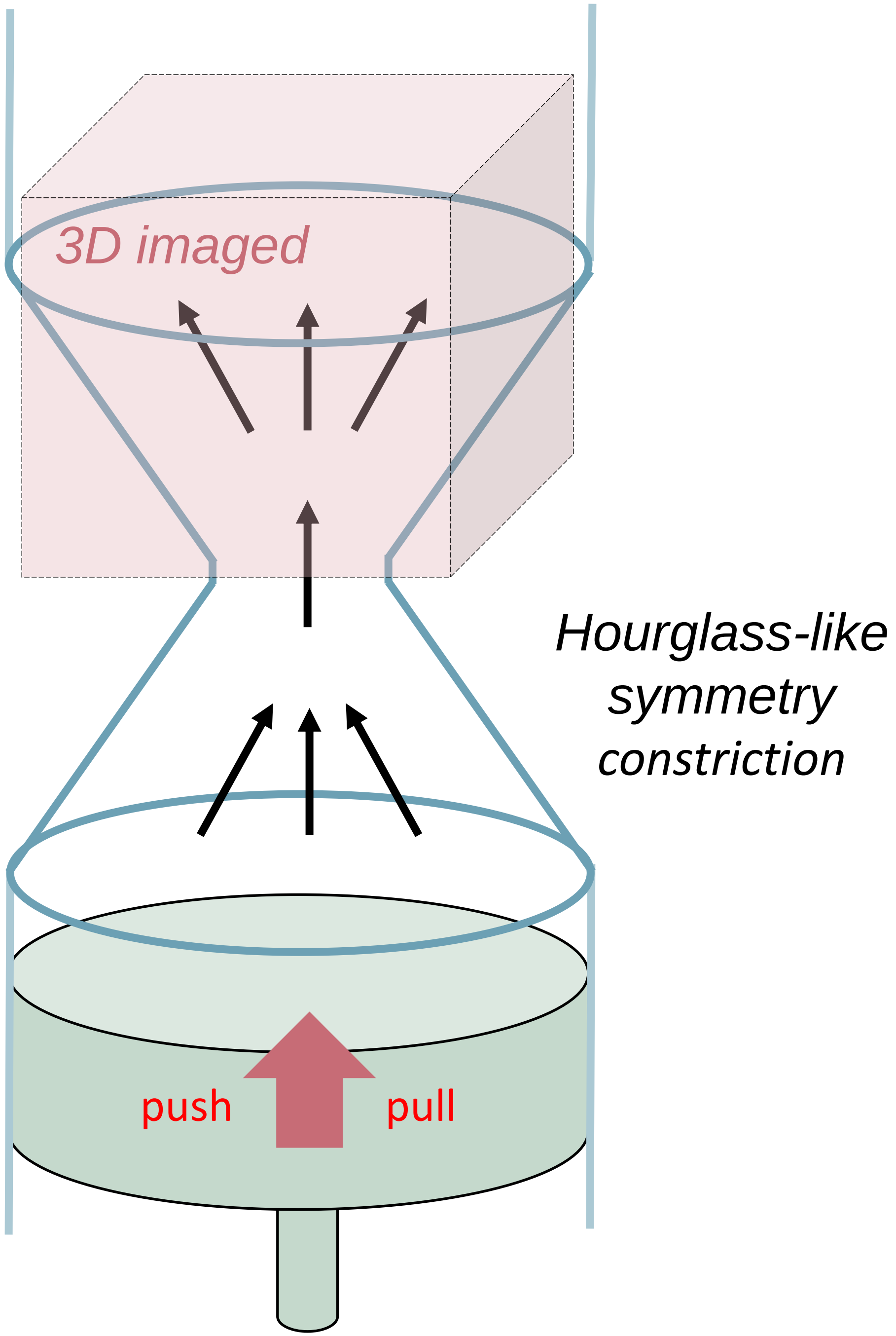
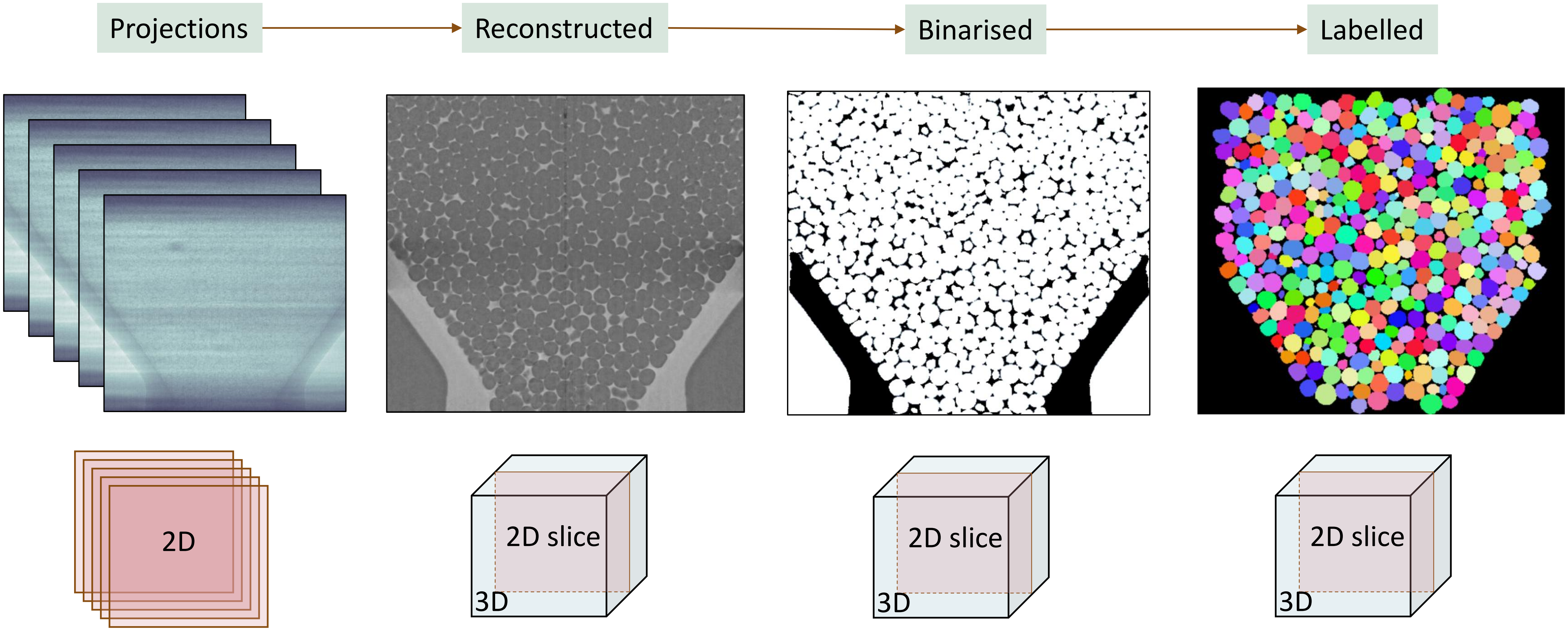
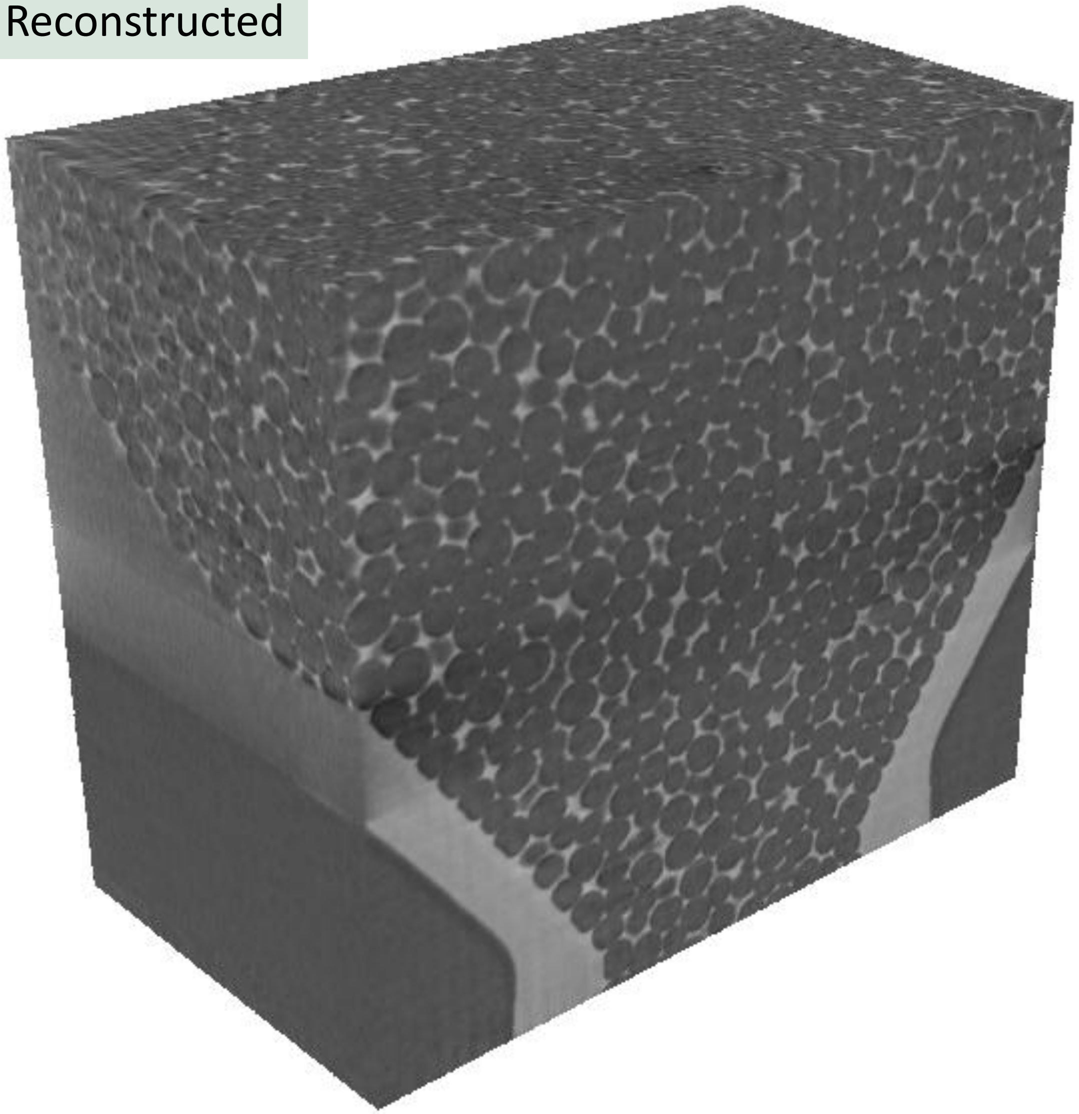


Image analysis – Workflow

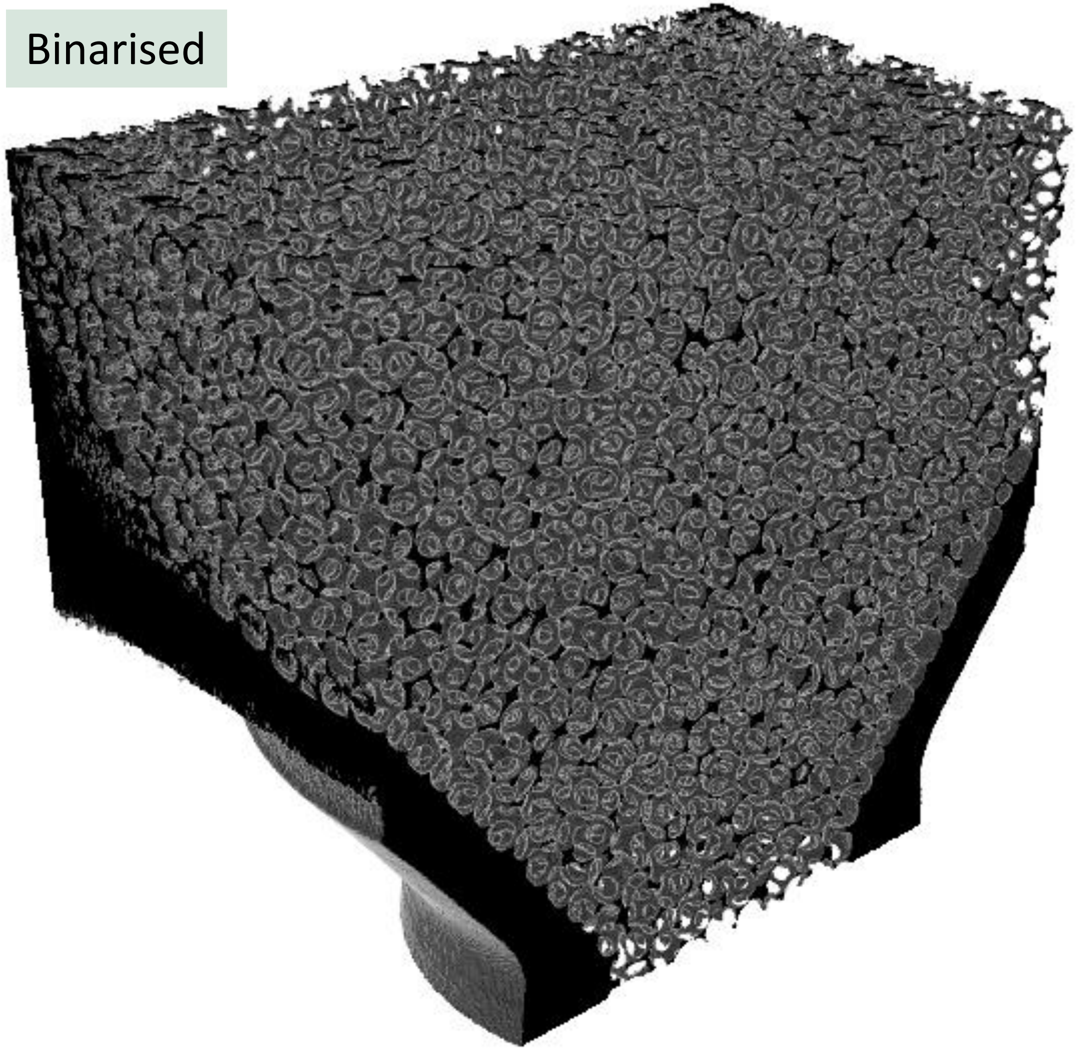


Images in 3D

Reconstructed

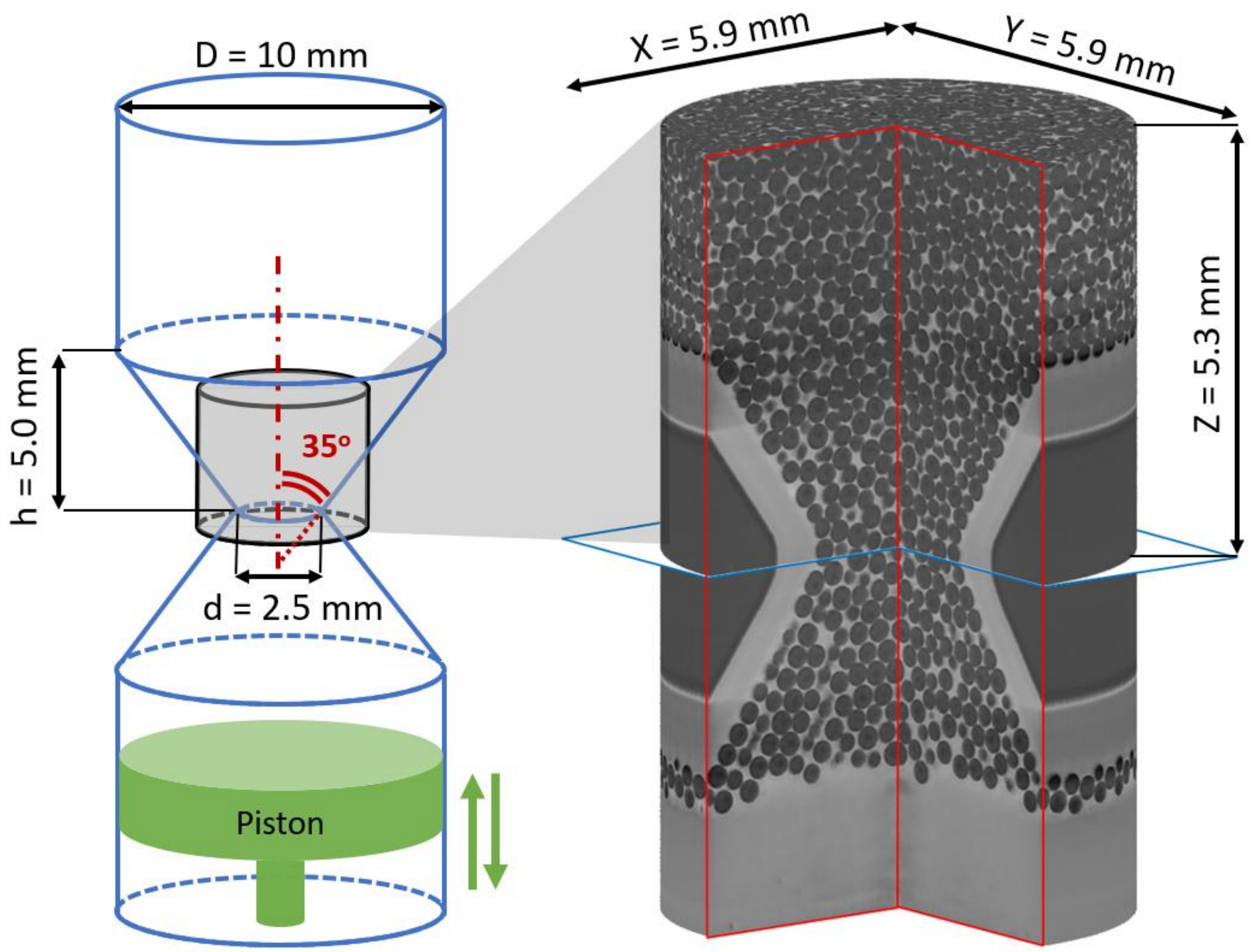


Binarised

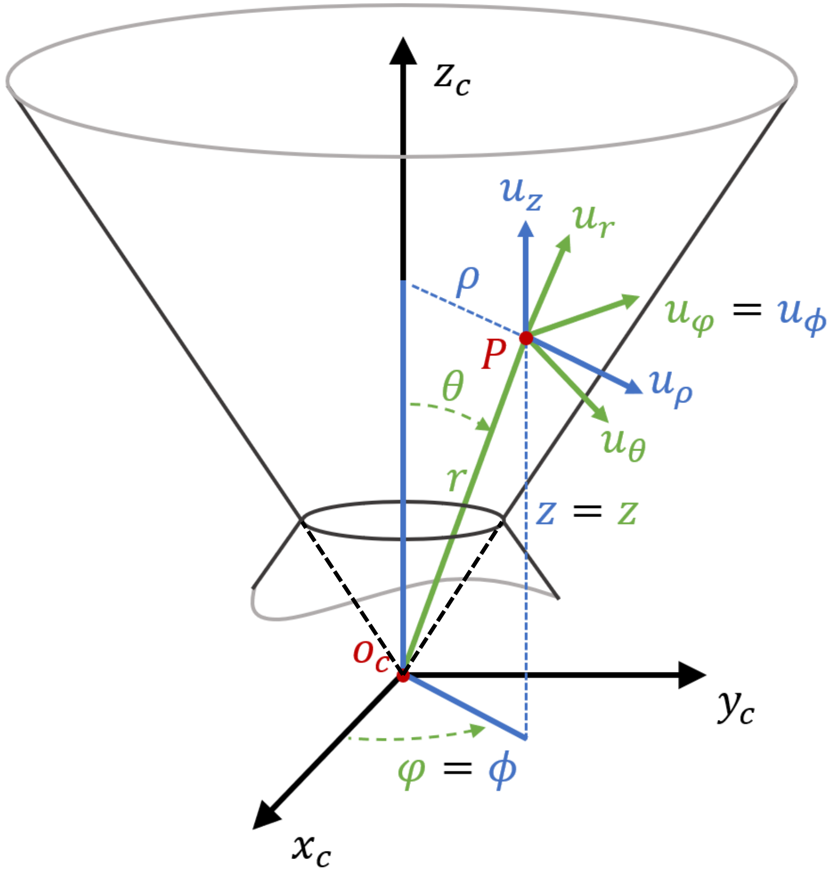


Results – Analysis of the flow

Dimensions: experiment and field of view

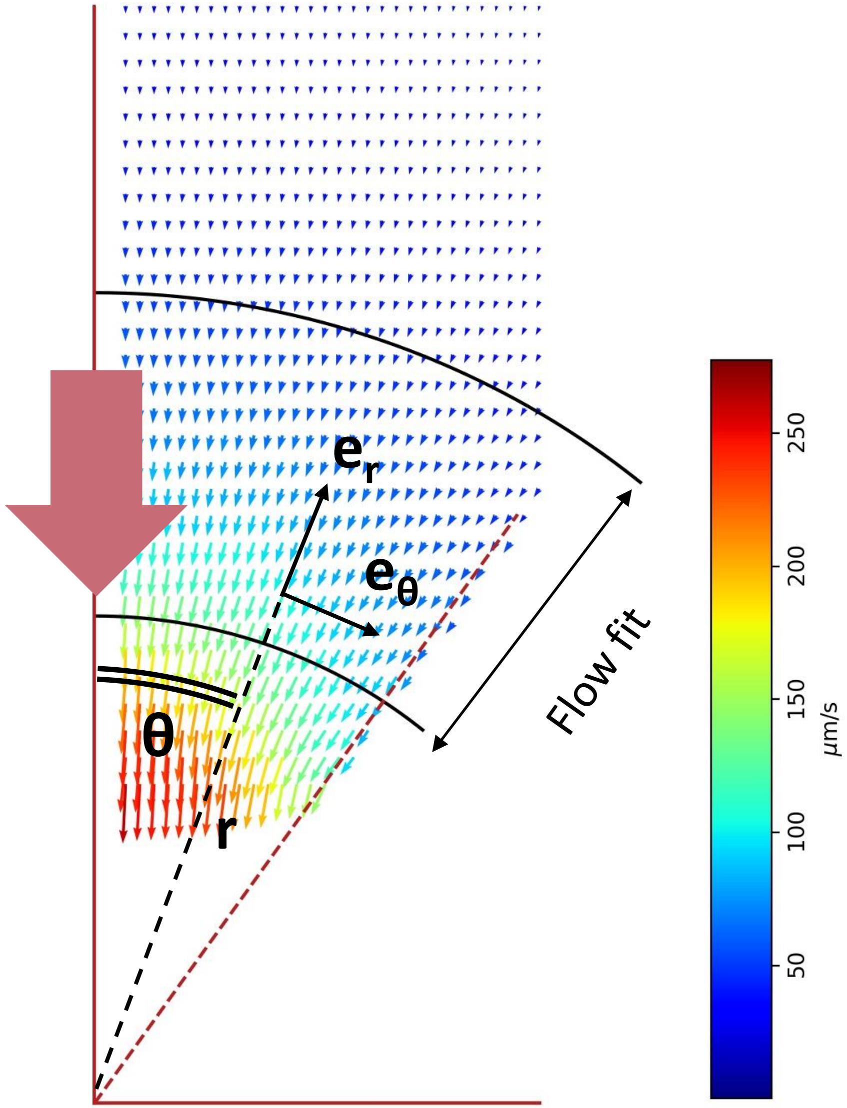


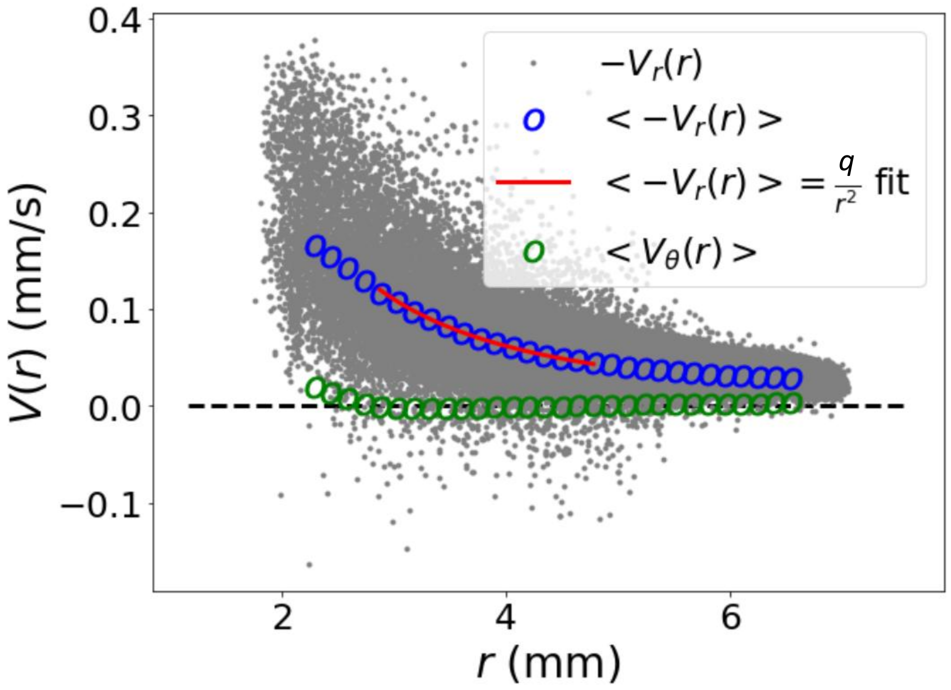
Cylindrical and spherical bases
centred on the virtual cone tip
henceforth spherical basis will be used



Results – Averaged flow field

42 Images: time and space average



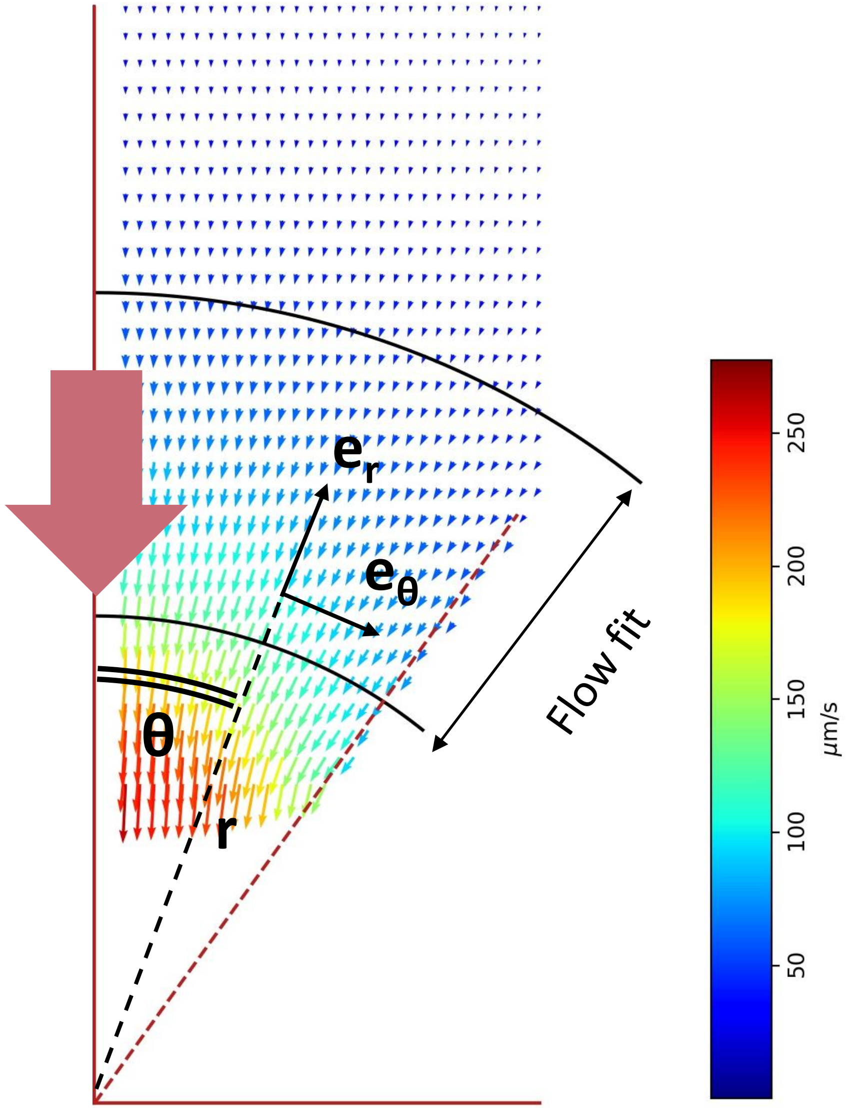


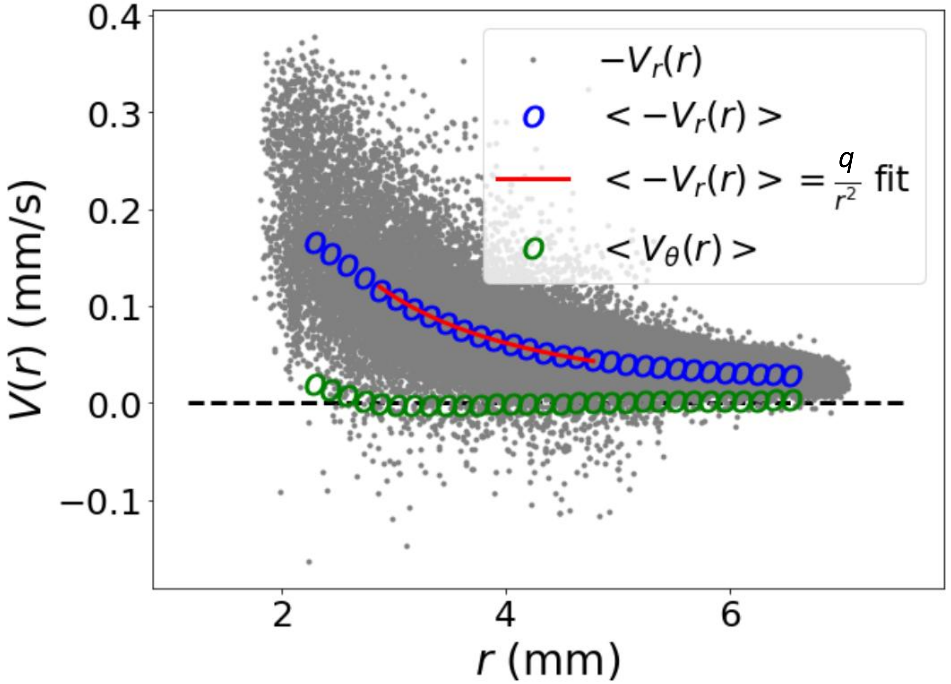
- ``pull'' experiment
- average bubble radius: 84 μm
- polydispersity: 44%
- liquid fraction: 28%

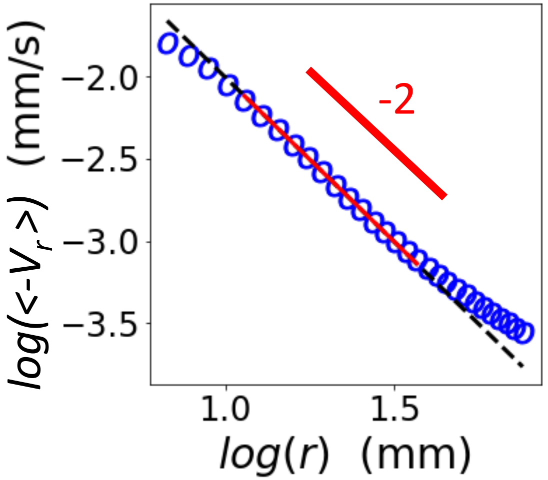
- individual data points: displacement of each bubble between two consecutive images
- large dispersion!
- but everything smoothes out once averaged over time and spherical coordinates θ and φ
- $1/r^2$ dependence: originates from volume conservation

Results – Averaged flow field

42 Images: time and space average







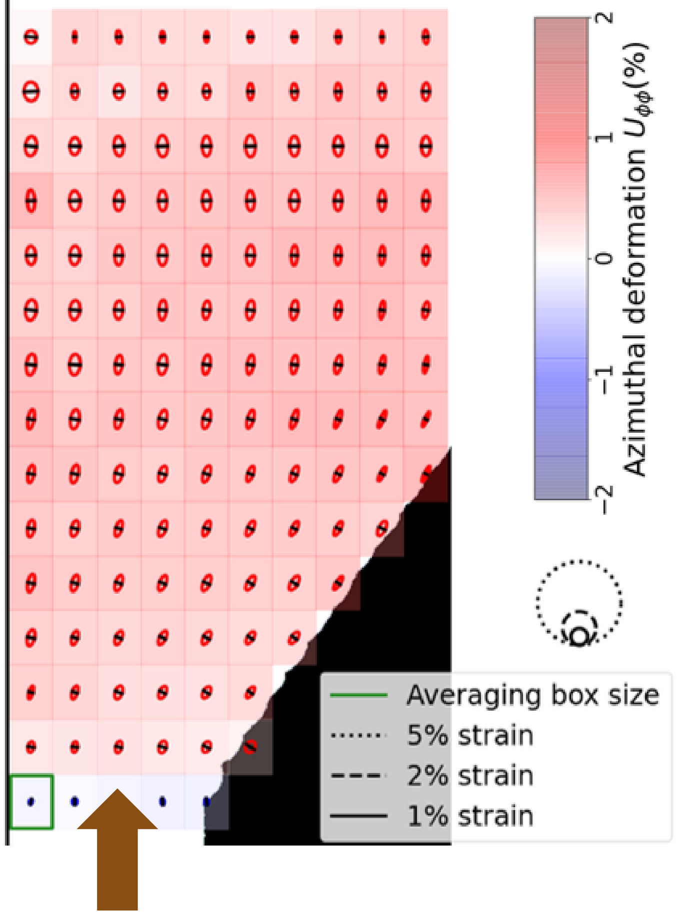
Spherical volume conservation flow

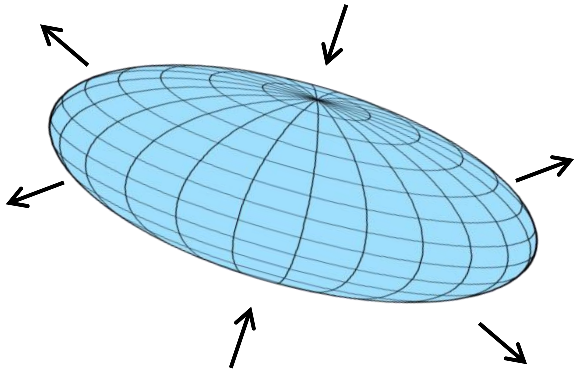
Reference flow with the same flow rate

$$\overrightarrow{V_r(r)} = -\frac{q}{r^2}\overrightarrow{e_r}$$

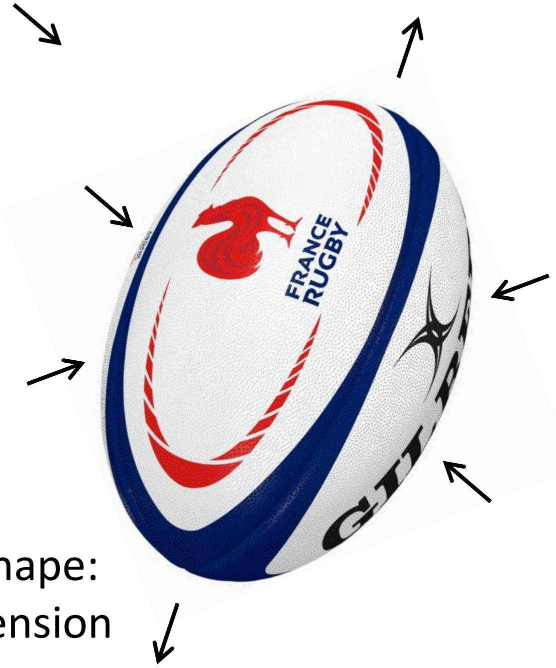
Results: deformation field

Push experiment



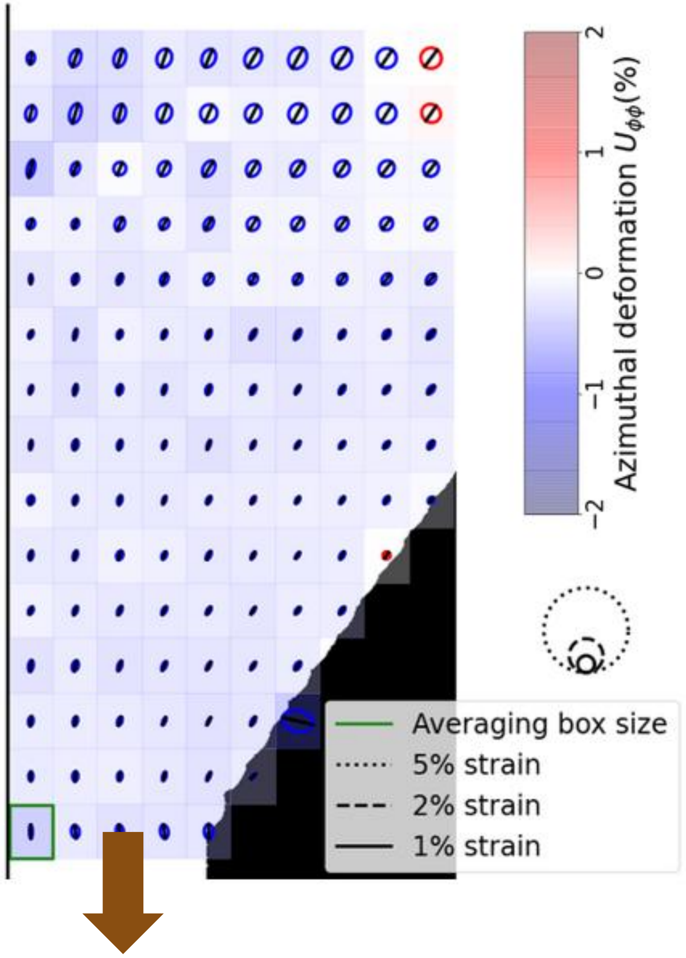


Oblate shape:
Axial contraction
$U_{rr} < 0$
Lateral extension
$U_{\theta\theta}, U_{\varphi\varphi} > 0$

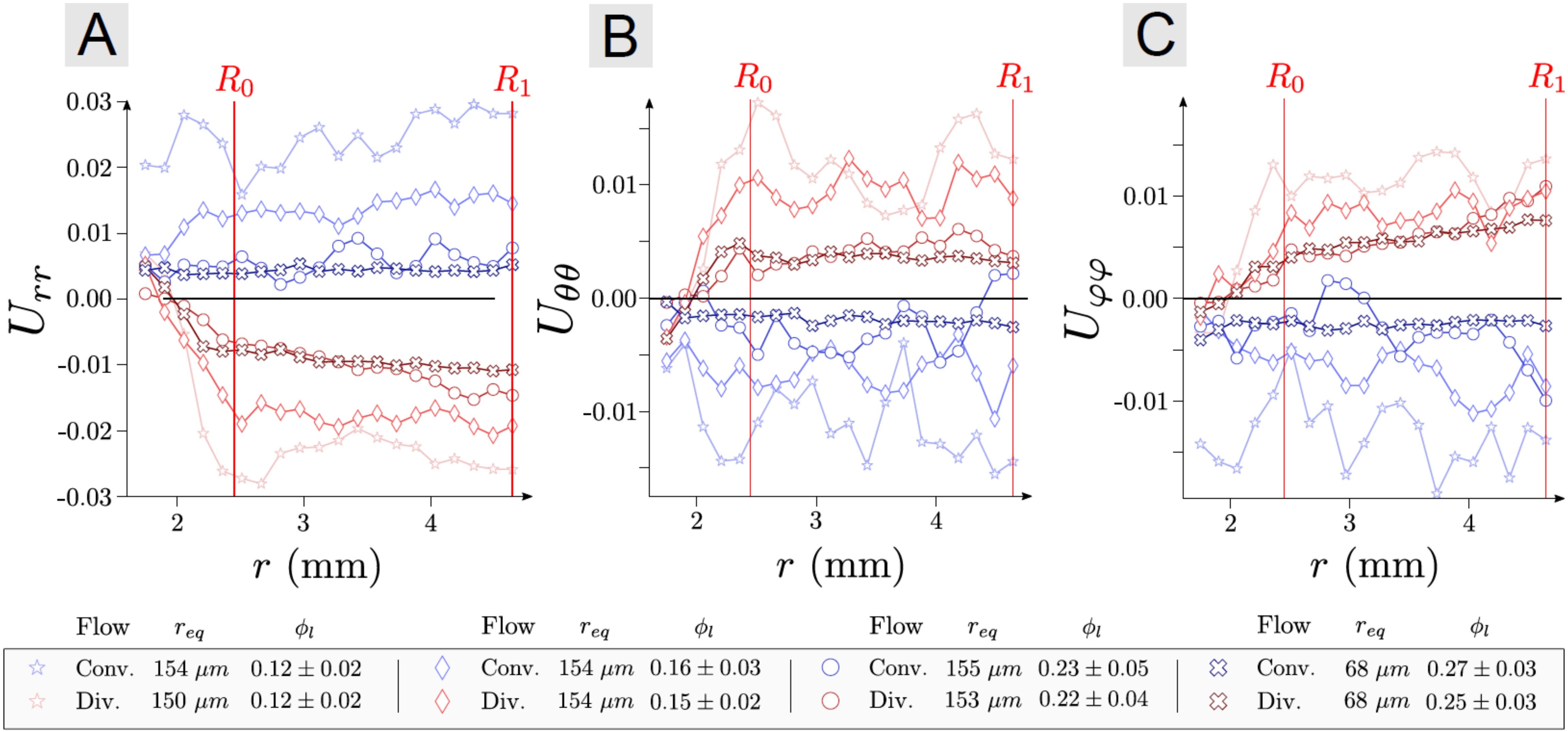


Prolate shape:
Axial extension
$U_{rr} < 0$
Lateral contraction
$U_{\theta\theta}, U_{\varphi\varphi} > 0$

Pull experiment

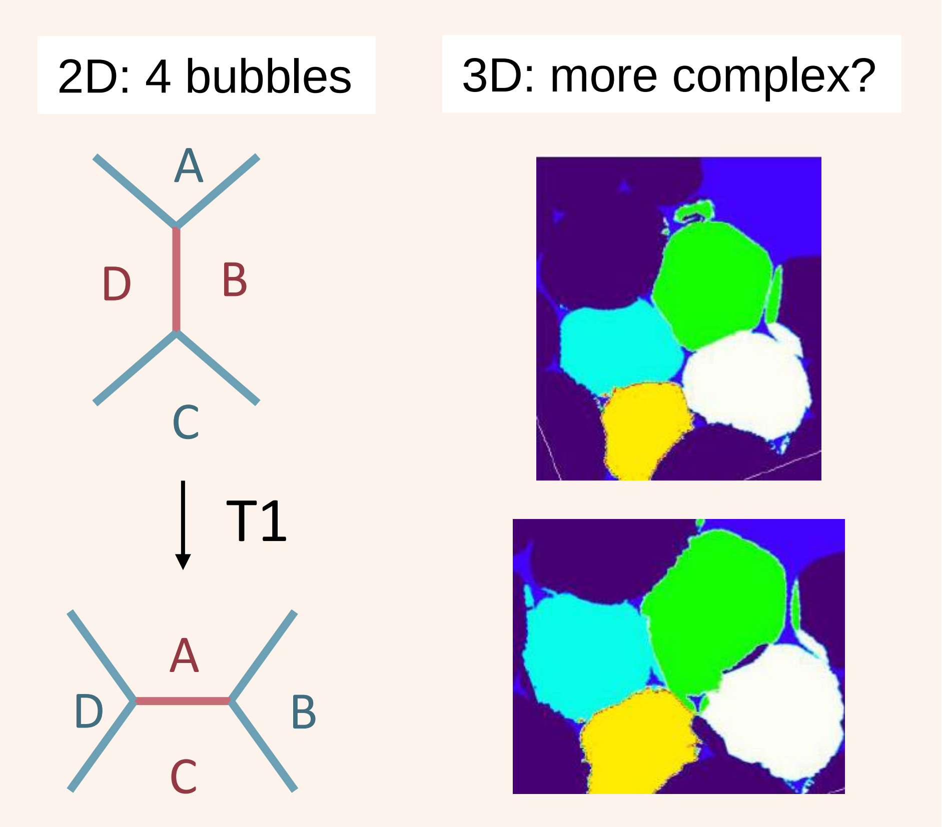


Results: deformation field



Ongoing work

Quantify the plastic events



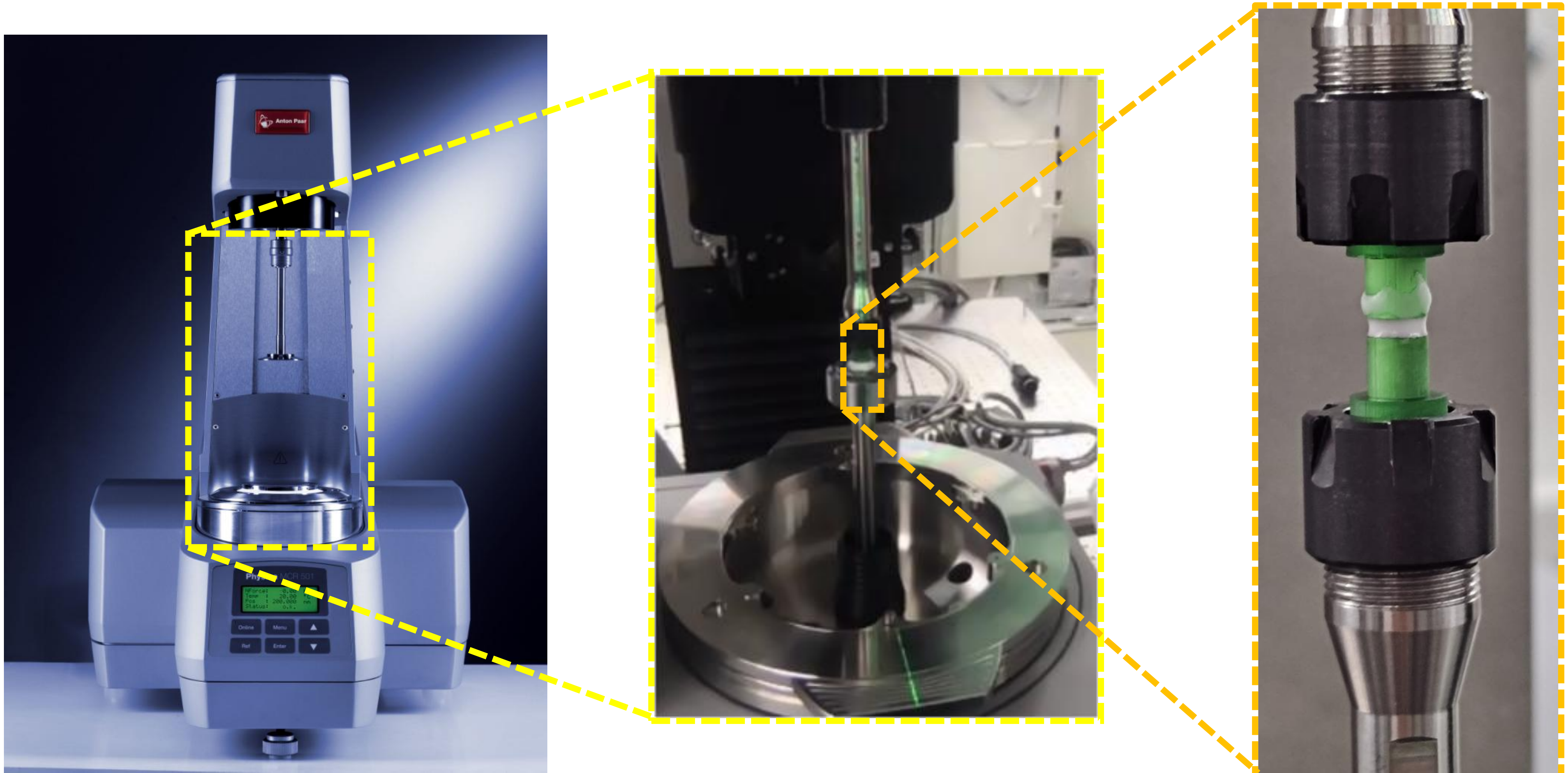
Source: C. Raufaste et al., EPL (2015)

Recent experiment

Coupling rheometry and tomographic real-time 3D imaging (with Stefan Gstöhl and Christian Schlepütz, PSI)

Take a rheometer:

Adapt it to the beamline:



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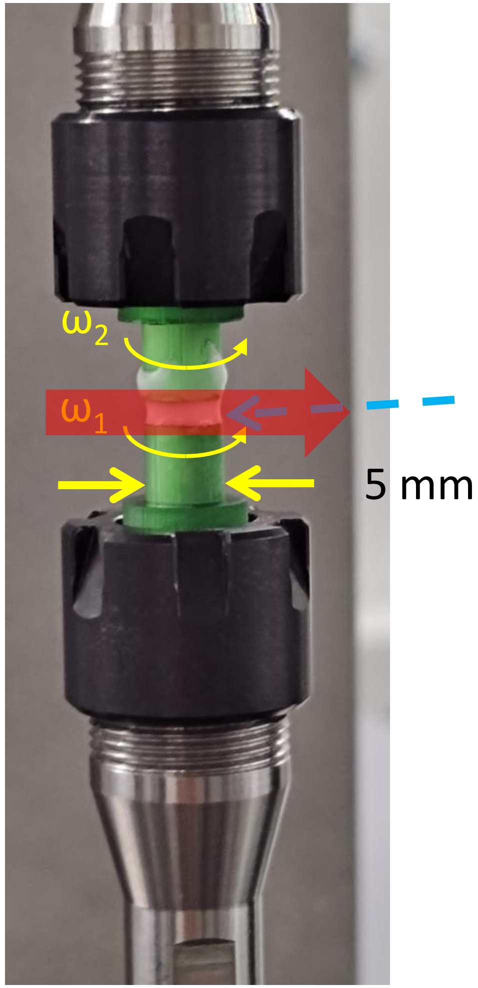

Two corotating parallel plates of diameter 5 mm:

- average rotation rate $(\omega_1 + \omega_2)/2$ for the tomography
- differential rotation rate $|\omega_1 - \omega_2|$ to apply strain

Foam inserted between the two plates
and illuminated by the beam