Sedimentation of objects in aqueous foams.

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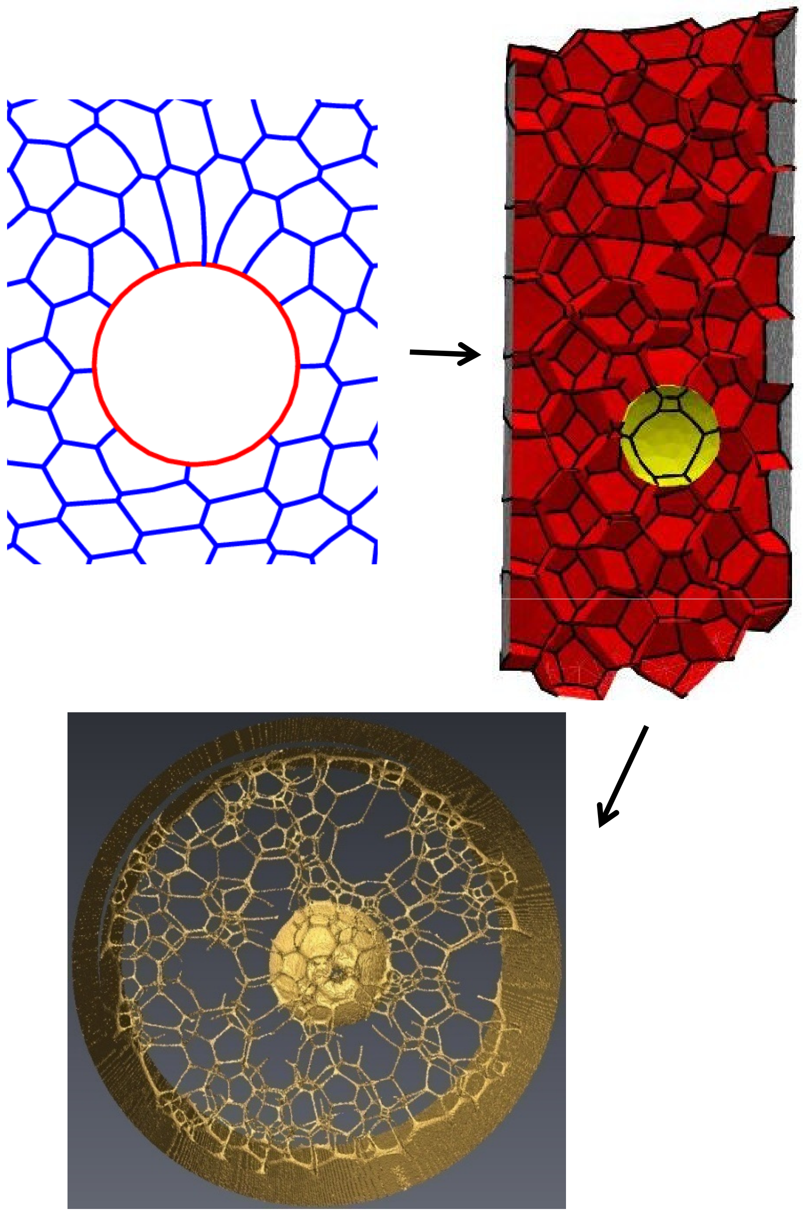
Simulating Stokes' experiment in a foam

1. Two-dimensional

- Theory and visualization of the flow is simplified.
- Computational time is minimized.

2. Three-dimensional

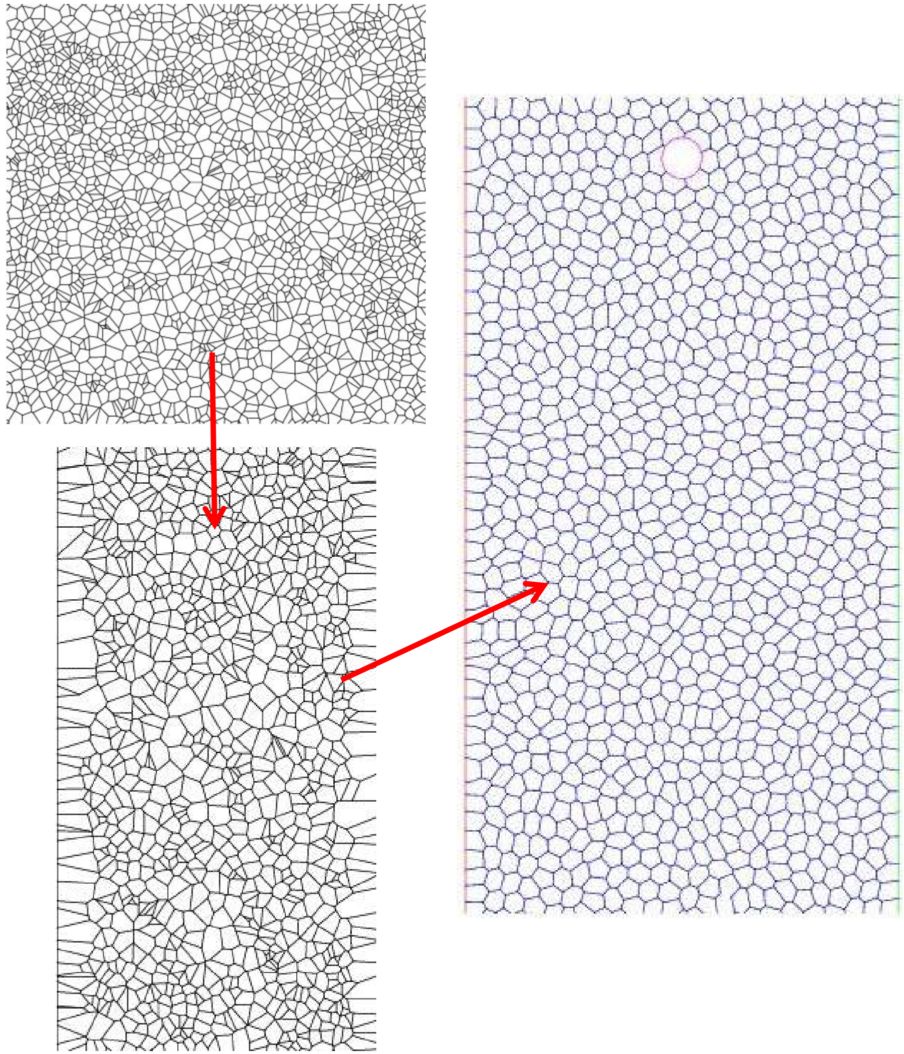
- More difficult to implement and visualize.
- To validate simulations we compare with experiments.



2D Simulations: Method

A structure that's topologically similar to a foam is built:

- Random **Voronoi** tessellation of the 2D unit square.
- Sequentially delete bubbles from either side and constrain outer edges to vertical walls.



The **Surface Evolver*** minimizes the structure's *total edge length* subject to the bubble *area* constraints:

$$E = \gamma \sum_{films\ i} l_i + \sum_{bubbles\ k} p_k \left(A_k - A_k^t \right)$$

*www.susqu.edu/brakke/evolver

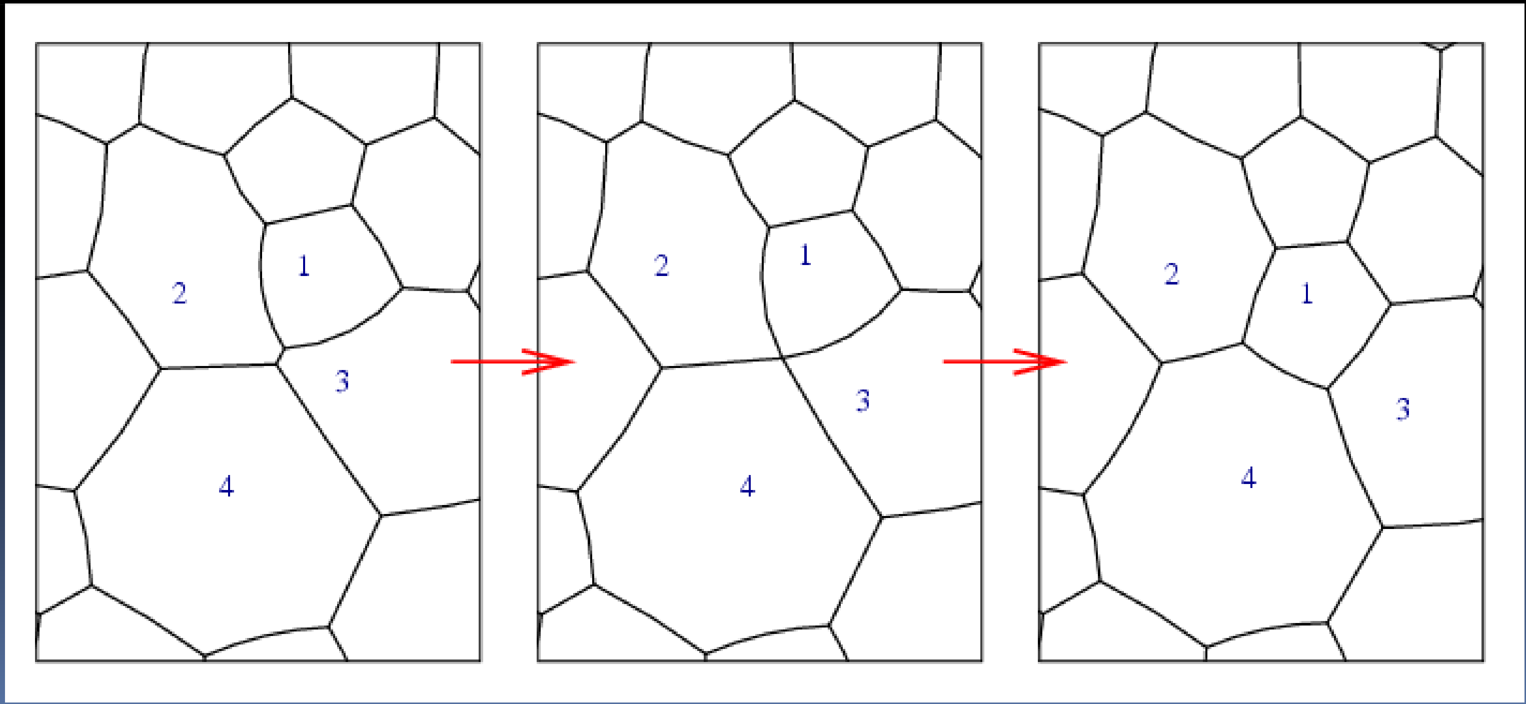
T1 events in 2D Simulations

- Define a cut-off length l_c.
- Delete any edge that shrinks below this length.
- Insert a new edge in the perpendicular direction.

Note: The cut-off length relates to the effective liquid fraction:

$$\Phi_l \approx 0.242 \frac{l_c^2}{A_b}$$

S. J. Cox et al. Rheol Acta, 43, 2004



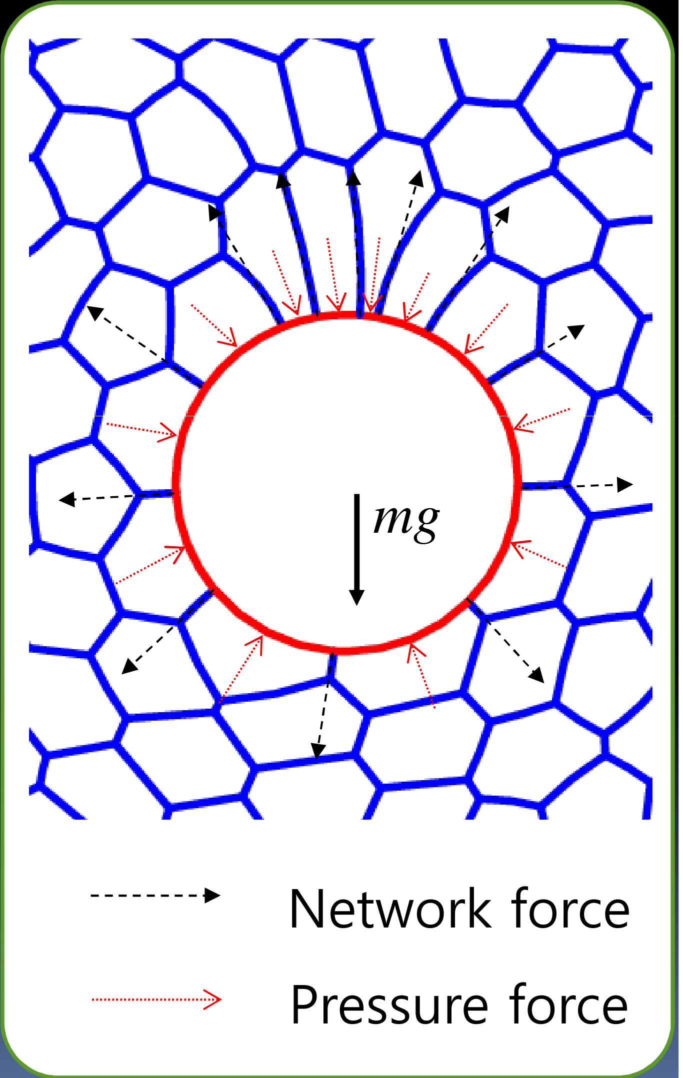
Quasi-static model

- Motion of an object in a foam is governed by Newton's 2nd law of motion:

$$m\frac{d\vec{x}^2(t)}{dt^2} = mg\vec{z} - \lambda\frac{d\vec{x}(t)}{dt} + \vec{F}^p + \vec{F}^n$$

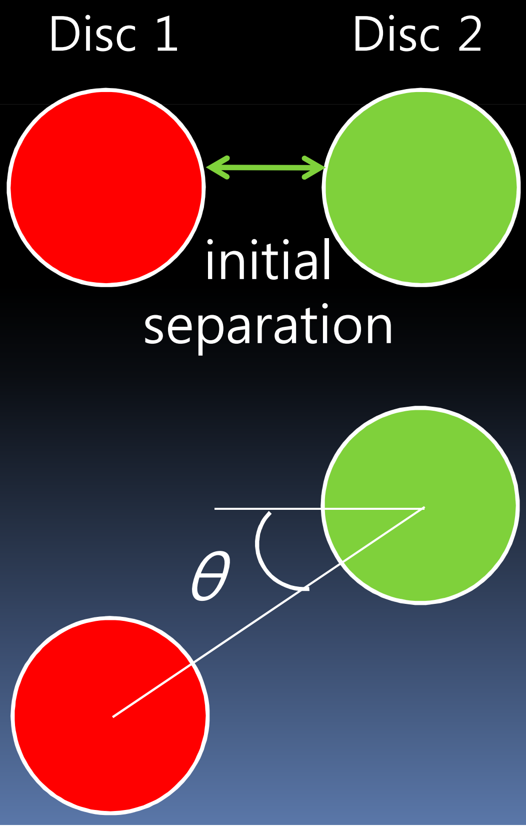
- We assume that the motion is **slow** and **steady**.
- The foam is in equilibrium between very small increments in the position of the object.
- A small constant epsilon ($\varepsilon = 1/\lambda$) is chosen that sets the effective time scale of our simulation.

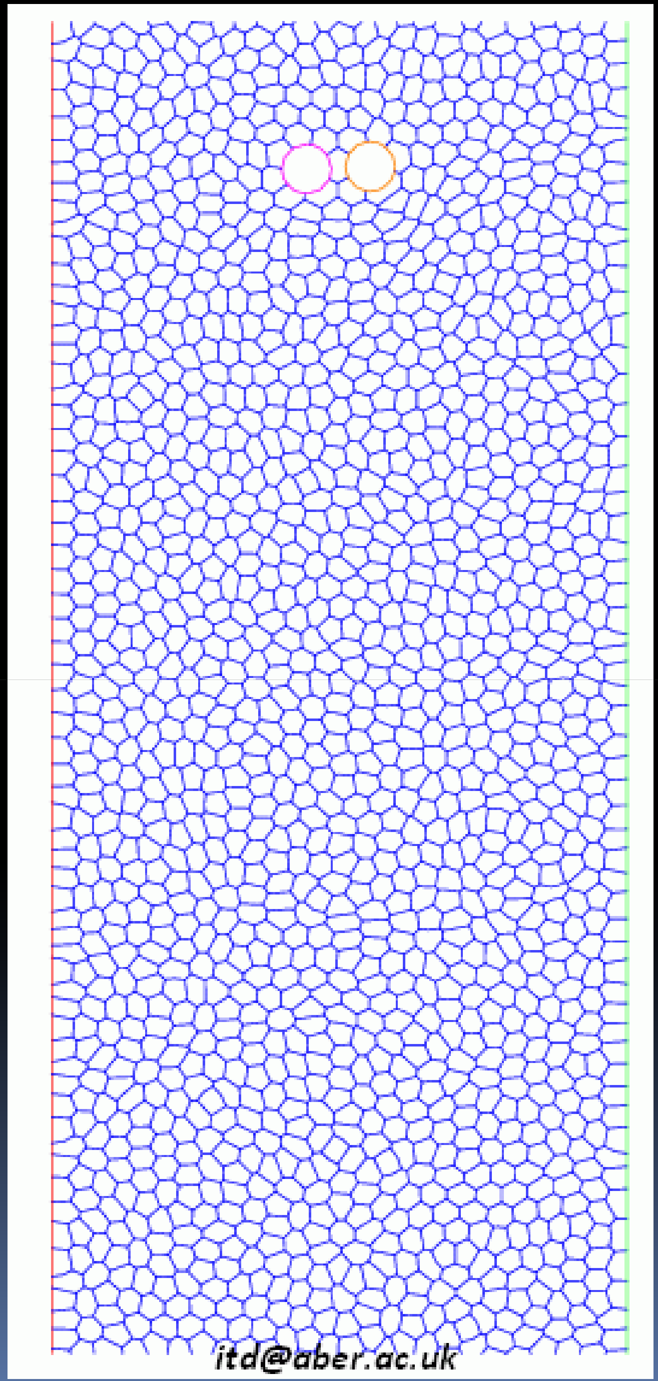
$$\frac{d\vec{x}(t)}{dt} = \varepsilon\left(mg\vec{z} + \vec{F}^p + \vec{F}^n\right)$$



Sedimentation of two circular discs:

Discs interact by rotating about each other to a stable configuration as they sediment.

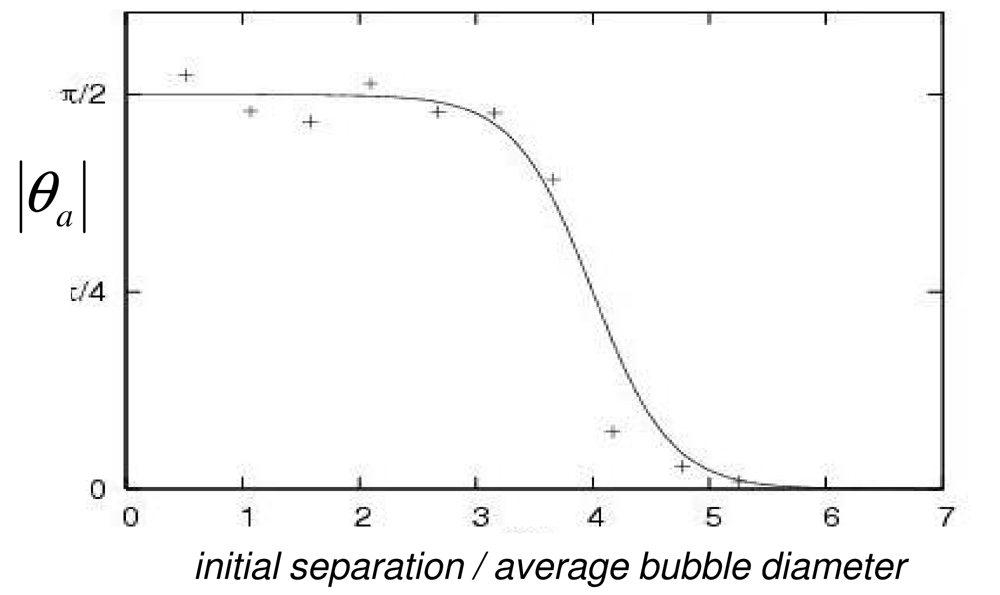


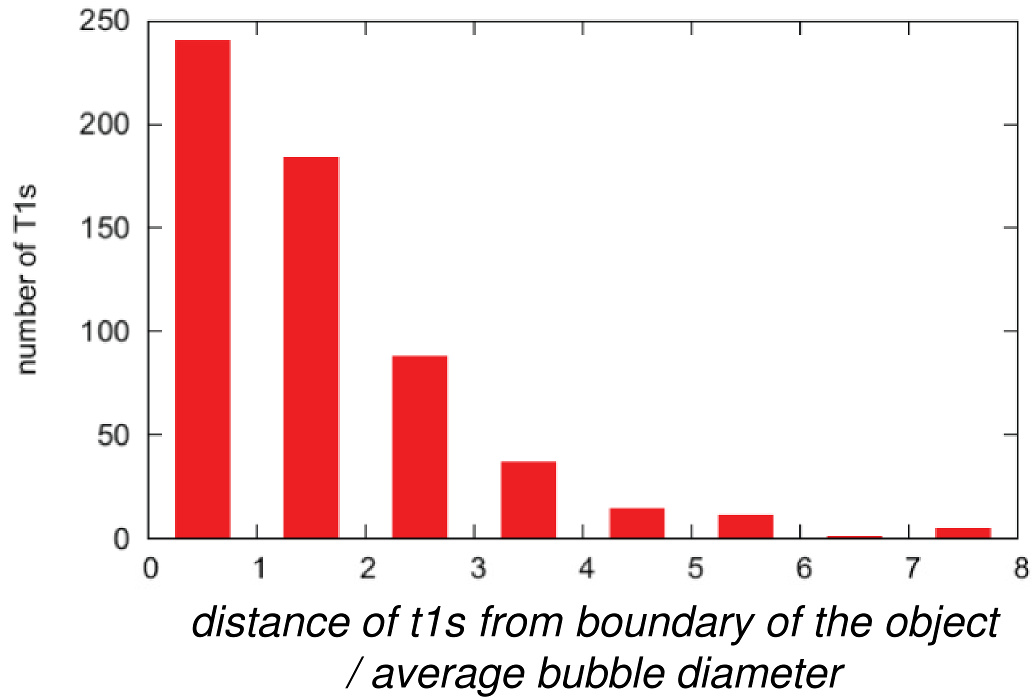


Interaction between circular discs:

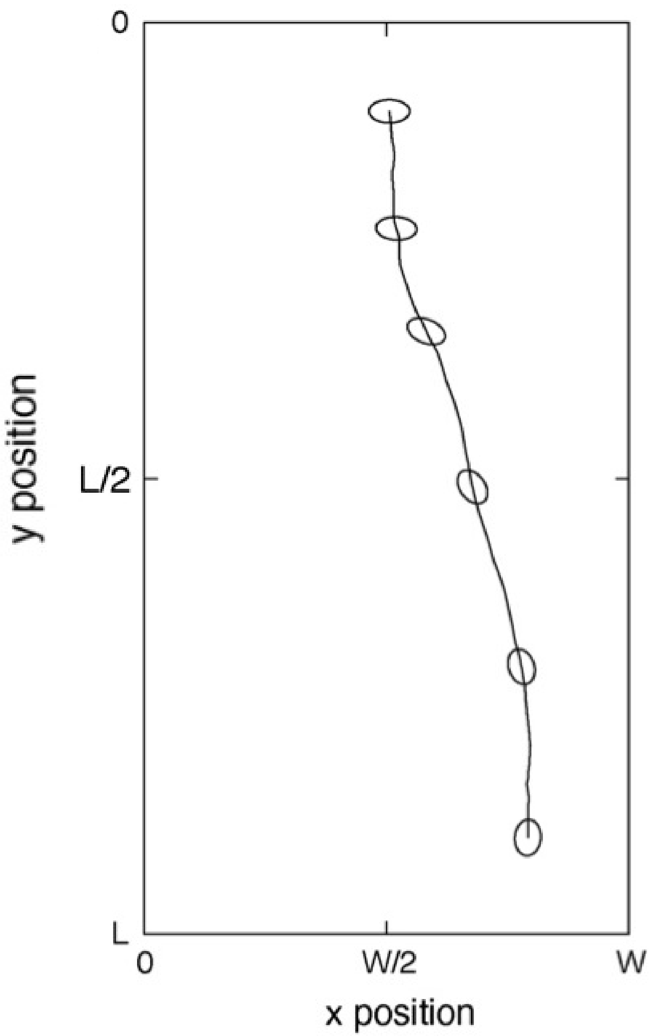
Let θ_a denote the value of θ at the bottom of the foam. The discs have fully interacted if $|\theta_a| \approx \pi/2$.

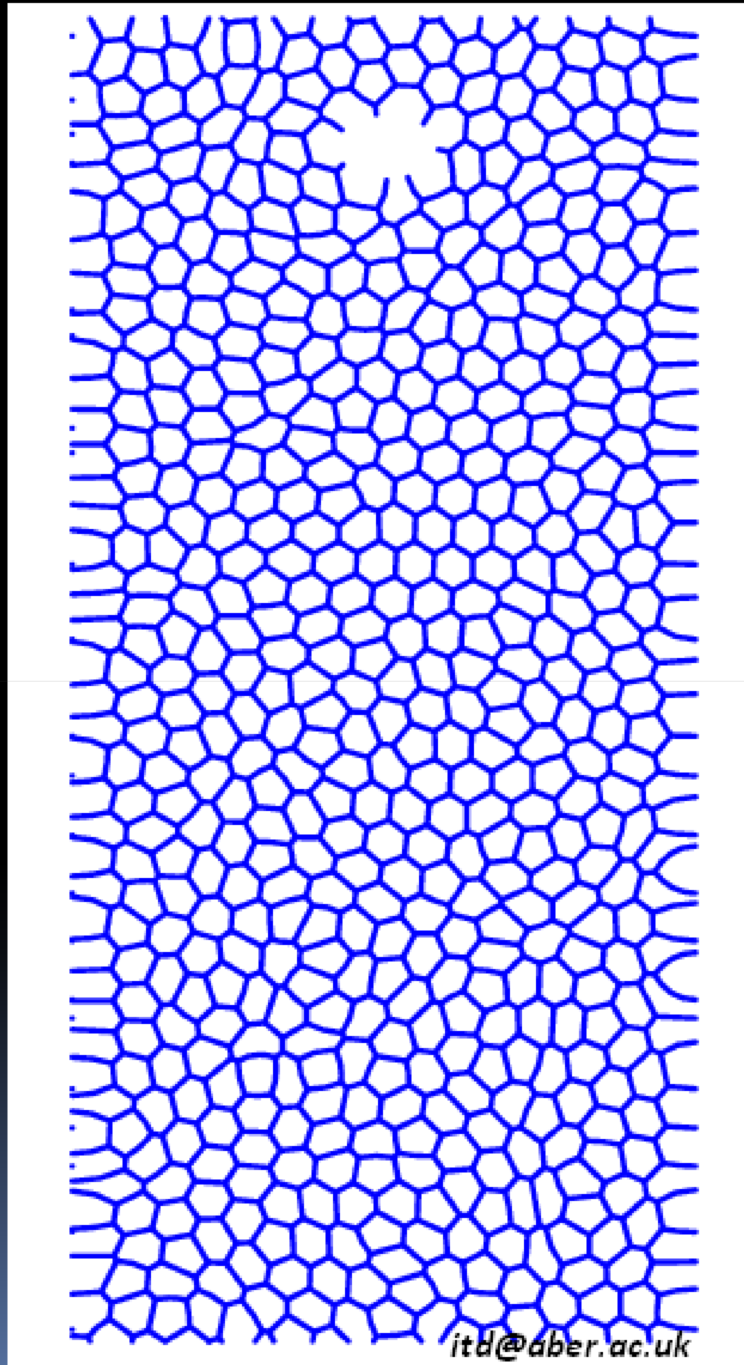
- A **critical separation** for disc-to-disc interaction exists due to the discrete nature of the foam.
- Objects interact in the foam if the **fluidized region** surrounding each object merge with each other.

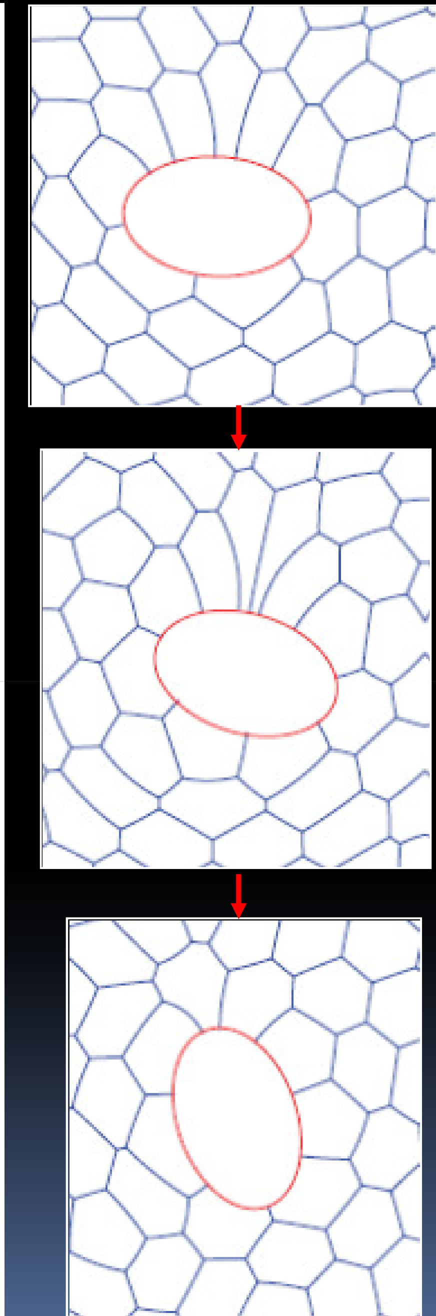




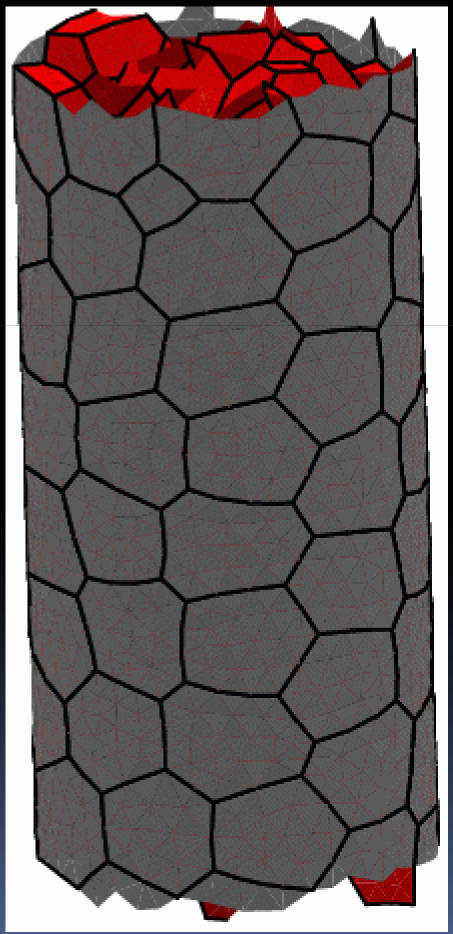
Sedimenting Ellipse:

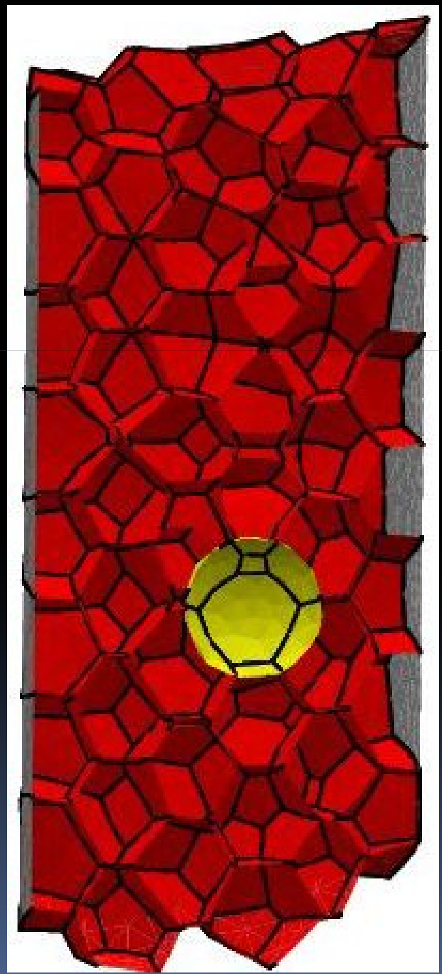






3D Simulations – Spheres in Disordered Foams





New challenges:

• Building initial disordered structures that have minimal surface area.

• T1 events in 3D.

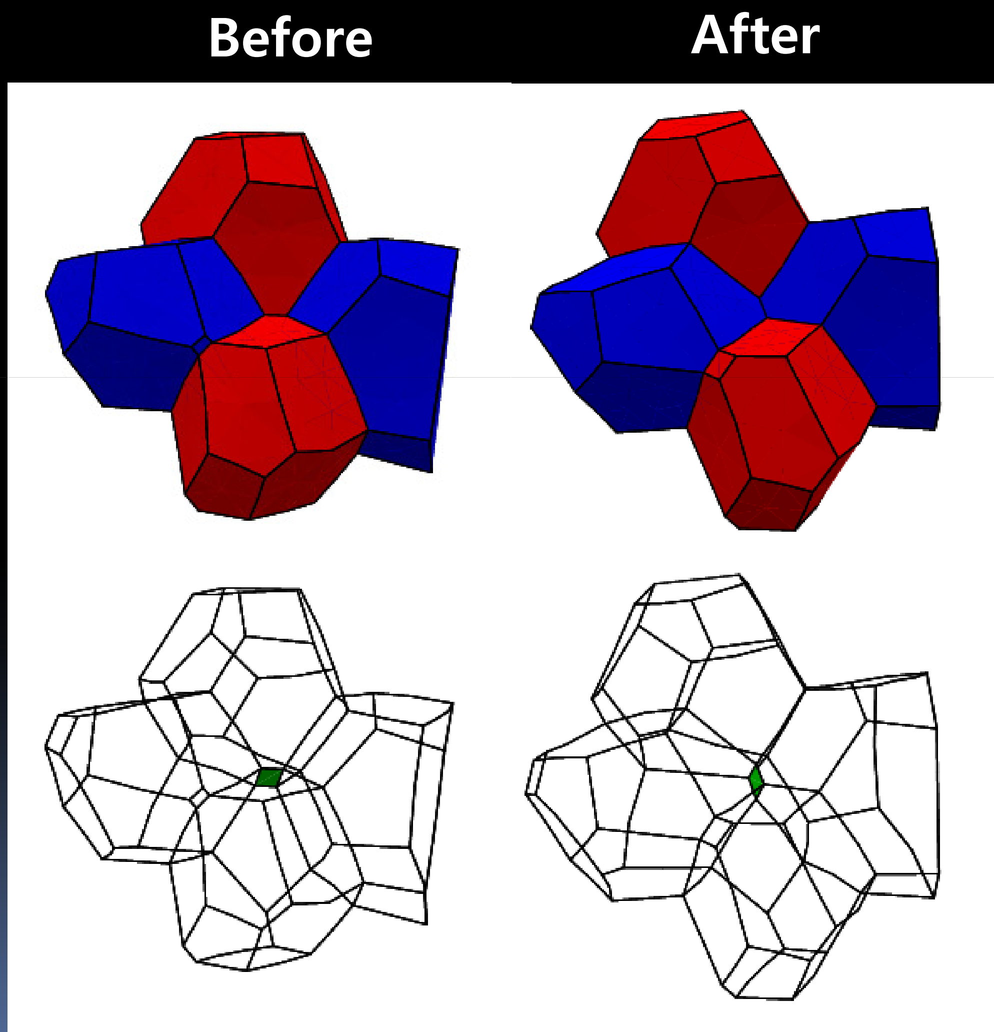
• Visualization of simulations is more complex.

T1 events in 3D simulations

- T1s are triggered when a facet shrinks below a predefined cut-off area a_c.

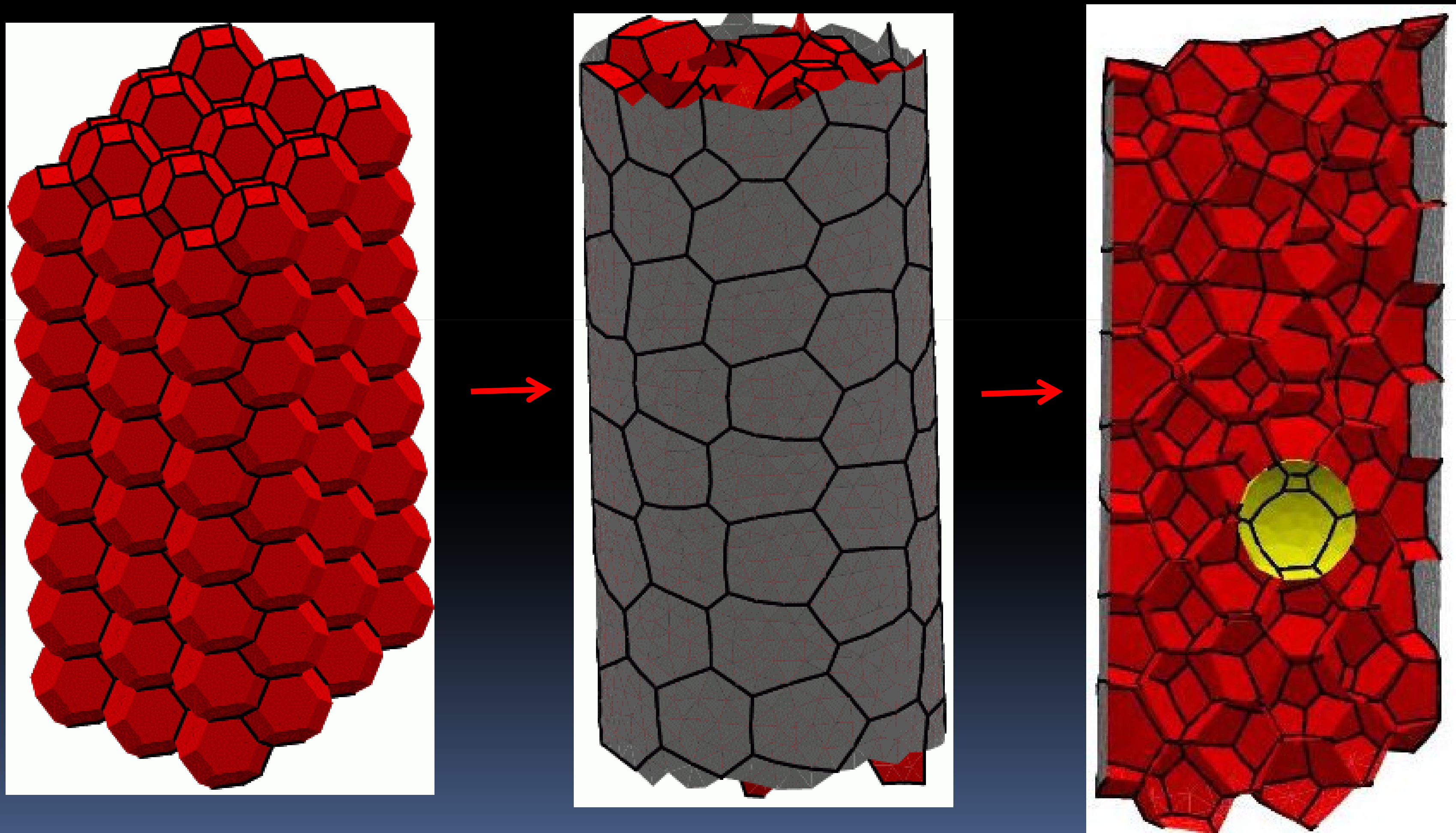
- Cut-off area defines the effective liquid fraction of the foam.

- We work with dry foams, where the liquid fraction $\Phi_l<1\%$.



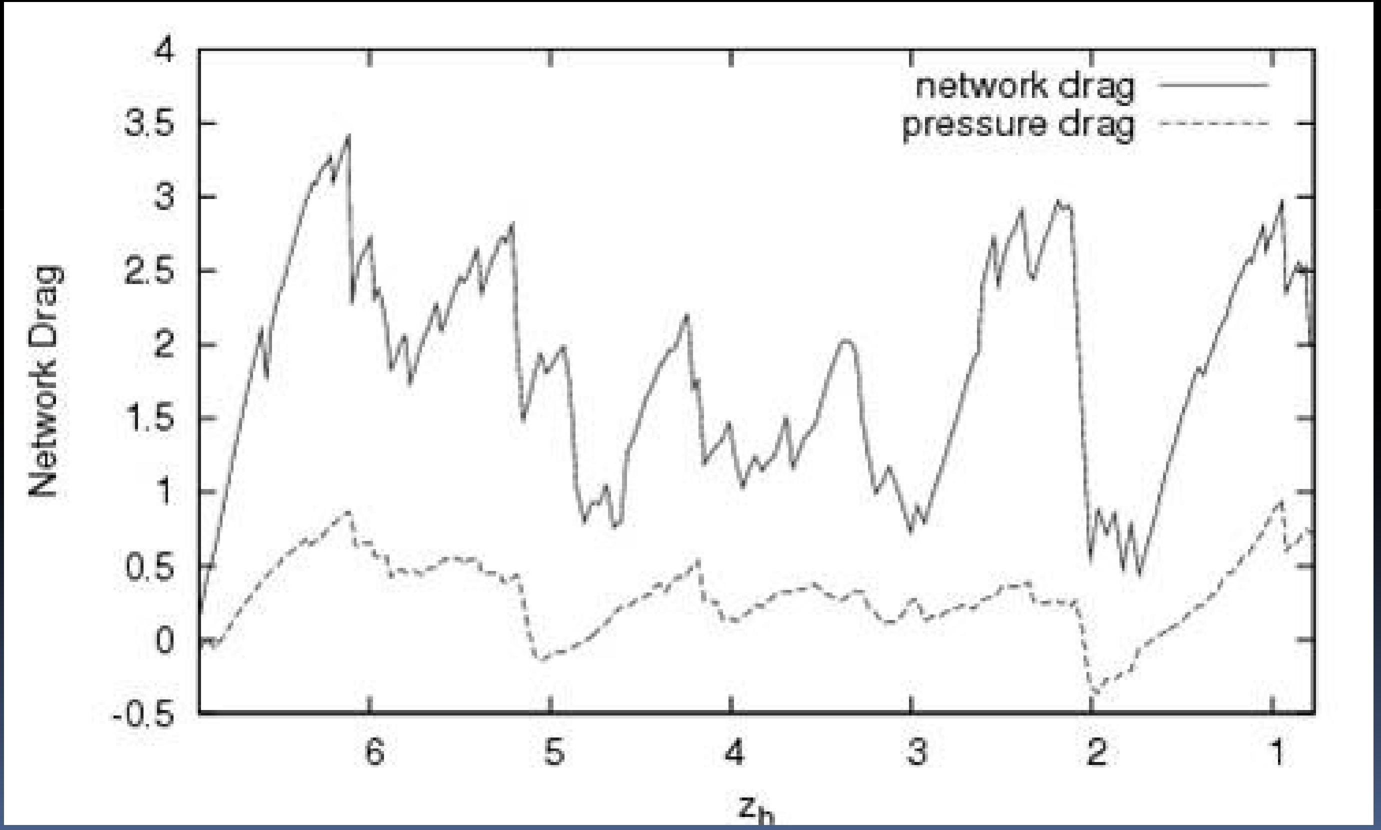
3D Simulations - Disordered Foams

Creation of the structure:



Variation of the drag force on the sphere

Network and pressure drag components fluctuate as
• bubbles detach and attach to the sphere due to t1s.
• contacting bubble pressures varies due to the deformation caused by the sphere.

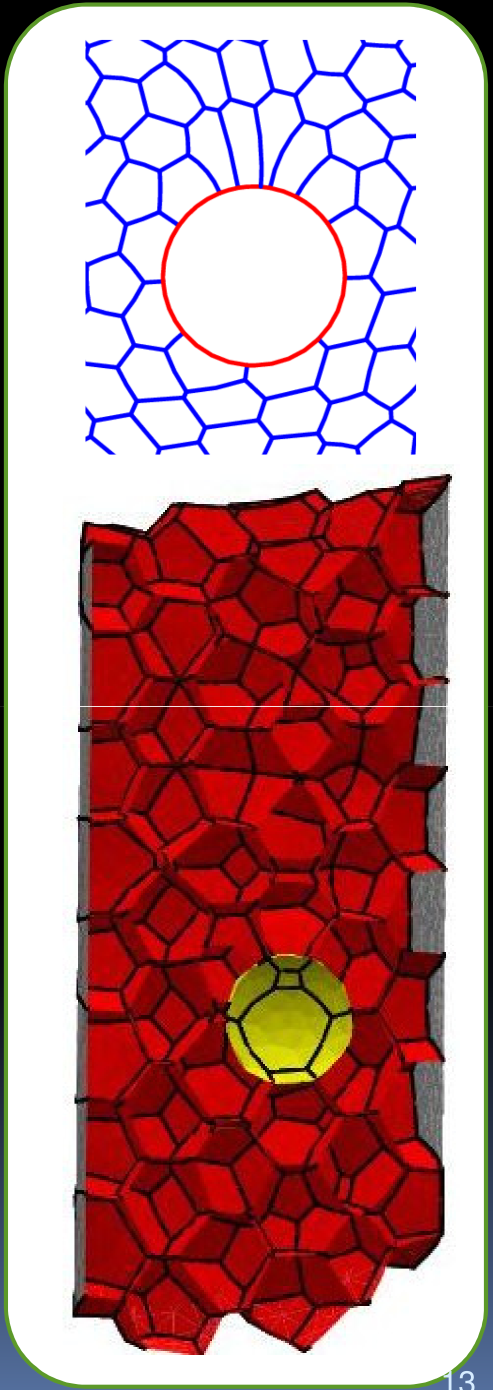


Validation of Simulations

Our simulations need to be validated by comparing with experiment.

Limitations of the simulations to be investigate include

- the effect of **viscous dissipation**.
- the effect of **bubble volume dispersity**.
- variation of the **liquid fraction**.



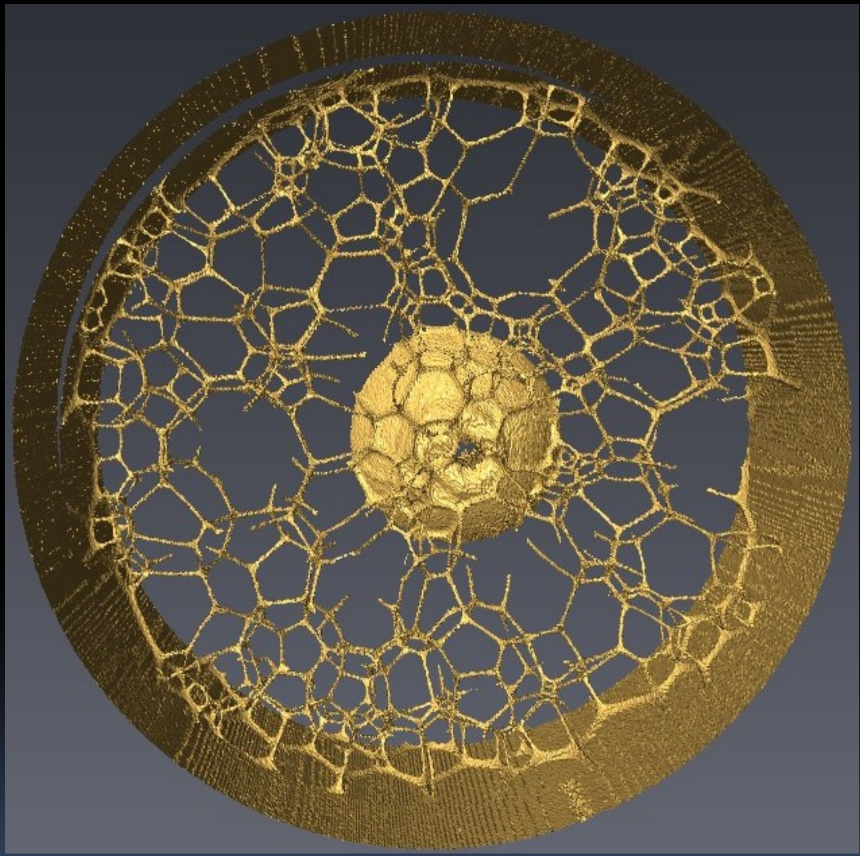
Validation of Simulations

Data available of equivalent experiment obtained from X-ray tomography.

- **Films aren't observed.**

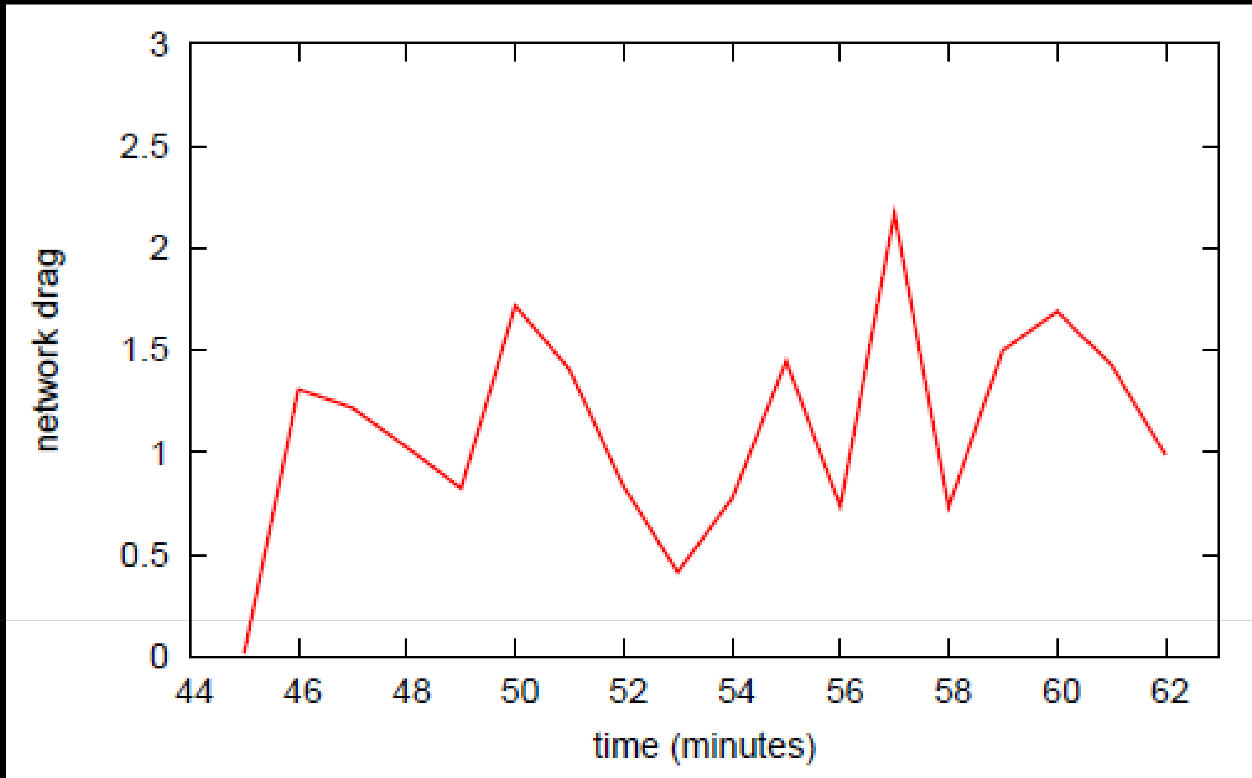
- A **partial reconstruction** of the foam can provide some validation for our simulations.

- e.g. Extracting the network of Plateau borders in contact with the sphere provides us with the **network force** exerted.



J. Lambert et al, Coll. Surf. A. 263 (2005)

Network force: 3D experiment



- Foam is dry as in simulation (liquid fraction is less than 3%).
- Flow is very slow – quasistatic approximation is appropriate.

Summary / Conclusions

- Progress in going from 2D to 3D simulations.
- 3D simulations of disordered foams are more challenging.
- Reconstruction of 3D disordered foams is required to validate.
- Only a partial reconstruction of the foam is required for calculation of the network force.