Prifysgol Cymru
Aberystwyth
1872 The University of Wales

INSTITUTO SUPERIOR TÉCNICO

2. TOPOLOGICAL INSTABILITIES OF DEFORMED BUBBLE CLUSTERS

M. Fátima Vaz

Simon Cox

Three-dimensional foams (3D):

- familiar from daily experience
- difficult to work (experimentally, analytically and simulations)

Two-dimensional foams (2D):

- easier experiments
- faster simulations
- some properties may be extended to 3D

NOT REALLY 2D FOAMS → QUASI-2D FOAMS

3 methods to produce 2D foams

Motivation:

1. 2D Couette shear experiment

Debregeas et al (2001) – an aqueous foam between two glass plates was sheared → shear band (topological changes confined)

Dennin et al (2002, 2004) – bubble raft → no shear band

2. **3D nature of the experimental systems**

- Cox et al (2003) – predicted topological changes may occur at different values because of the unaccounted liquid
  - meniscus beneath the bubbles
  - meniscus causes topological changes due to attraction between neighbouring vertices
  -these topological changes favours experimental configurations with higher 2D energy

- differences between the standards methods of producing 2D clusters suggest different behaviour of the instabilities (Vaz et al. 2004)

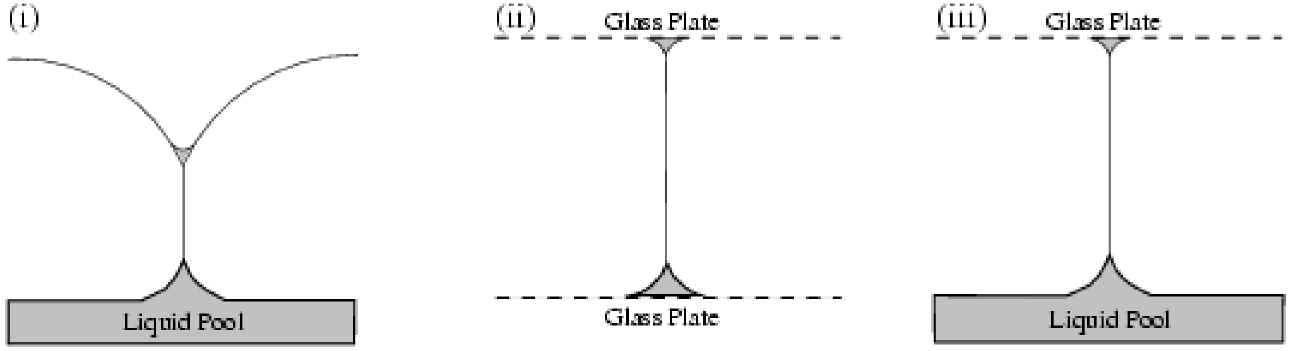
The distribution of liquid around the bubbles is not accounted in the standard dry theory

Liquid in the Plateau borders - (three films meet or a soap film touches a glass plate)

Liquid in the meniscus – (films meet the liquid surface)

Methods to produce 2D foams:

- **Bubble raft = *LA***
- **Hele-Shaw cell = *GG***
- **Liquid – glass = *LG***



LA ***GG*** ***LG***

1. **Bubble raft** = *LA* ; Bragg and Nye (1947) – behaviour of atoms

- single layer of bubbles on a liquid surface
- rapid bubble rupture

2. **Hele-Shaw cell** = *GG* = glass/glass method (Hele-Shaw 1898), Smith (1952), Glazier et al (1987)

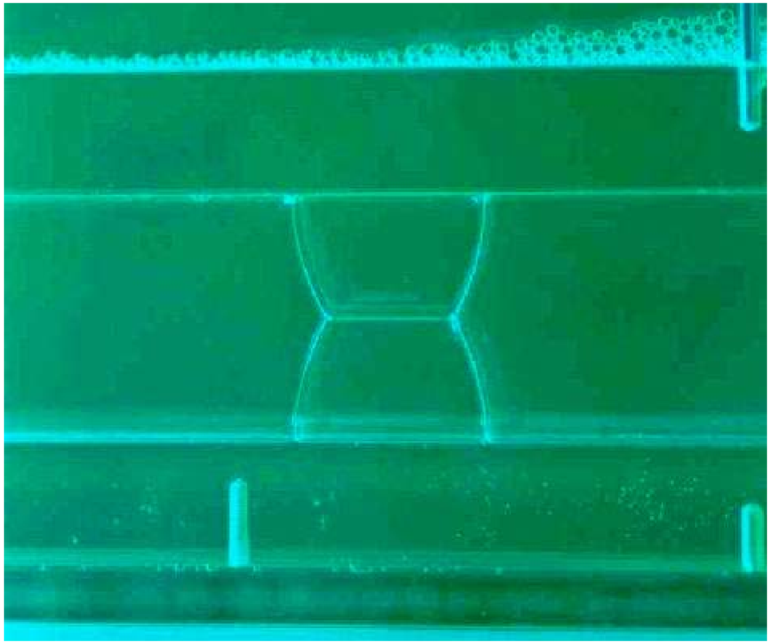
- layer of bubbles between two glass plates
- Plateau borders at top and bottom
- allows experiments with low liquid fraction
- difficult to produce arrangements of bubbles

3. **Liquid – glass** =*LG*, Smith (1952), Vaz and Fortes (1997), F. Graner,B. Dollet

- bubbles are trapped between a glass plate and a liquid solution
- Plateau borders in the top plate + meniscus at the base of each film
- easy to produce, many topological configurations, change H

Identical experiments with 3 systems – (effect of the system)

Deformation of two bubbles between two bars



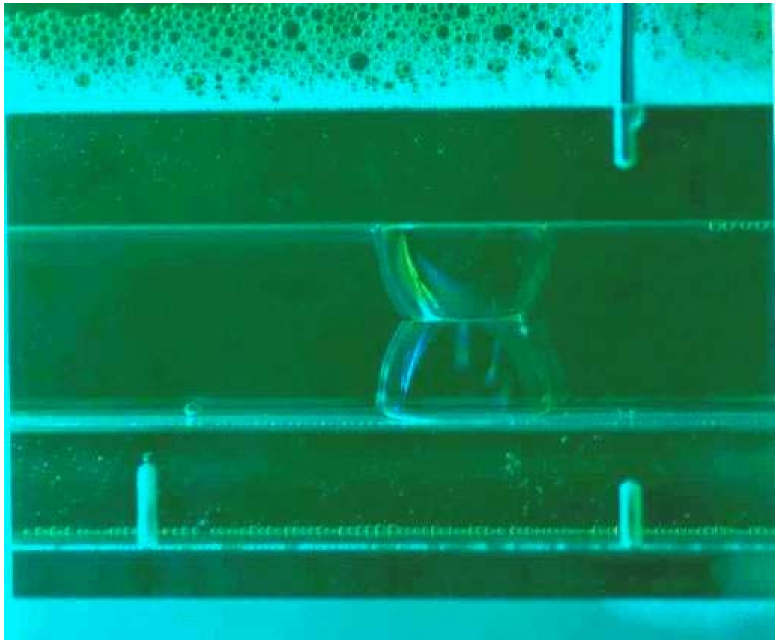
Liquid-glass method

- Two parallel bars penetrate into the liquid

-One bar is fixed; the other moves parallel to the fixed

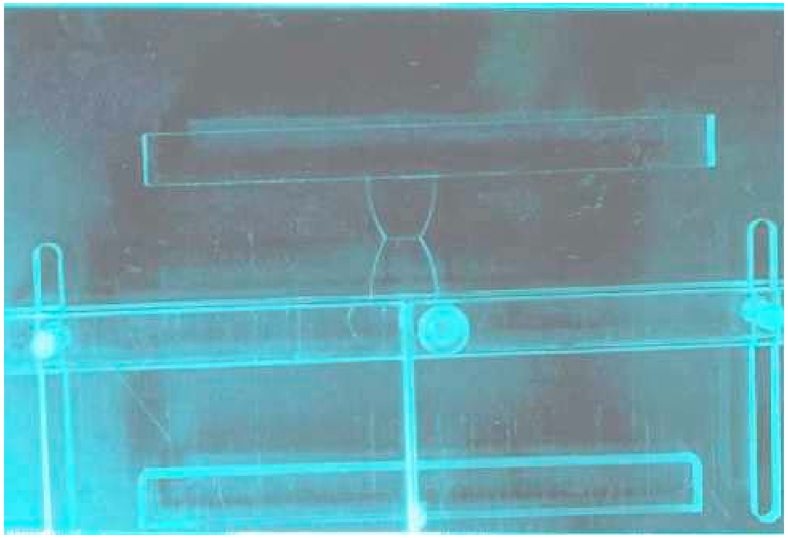
- 2 bubbles are produced with a syringe

- a glass plate covers the bars and the bubbles



Bubble raft

- Same procedure without covering plate



Glass-glass

-Bubbles are formed in a glass plate

-Covered with a second plate

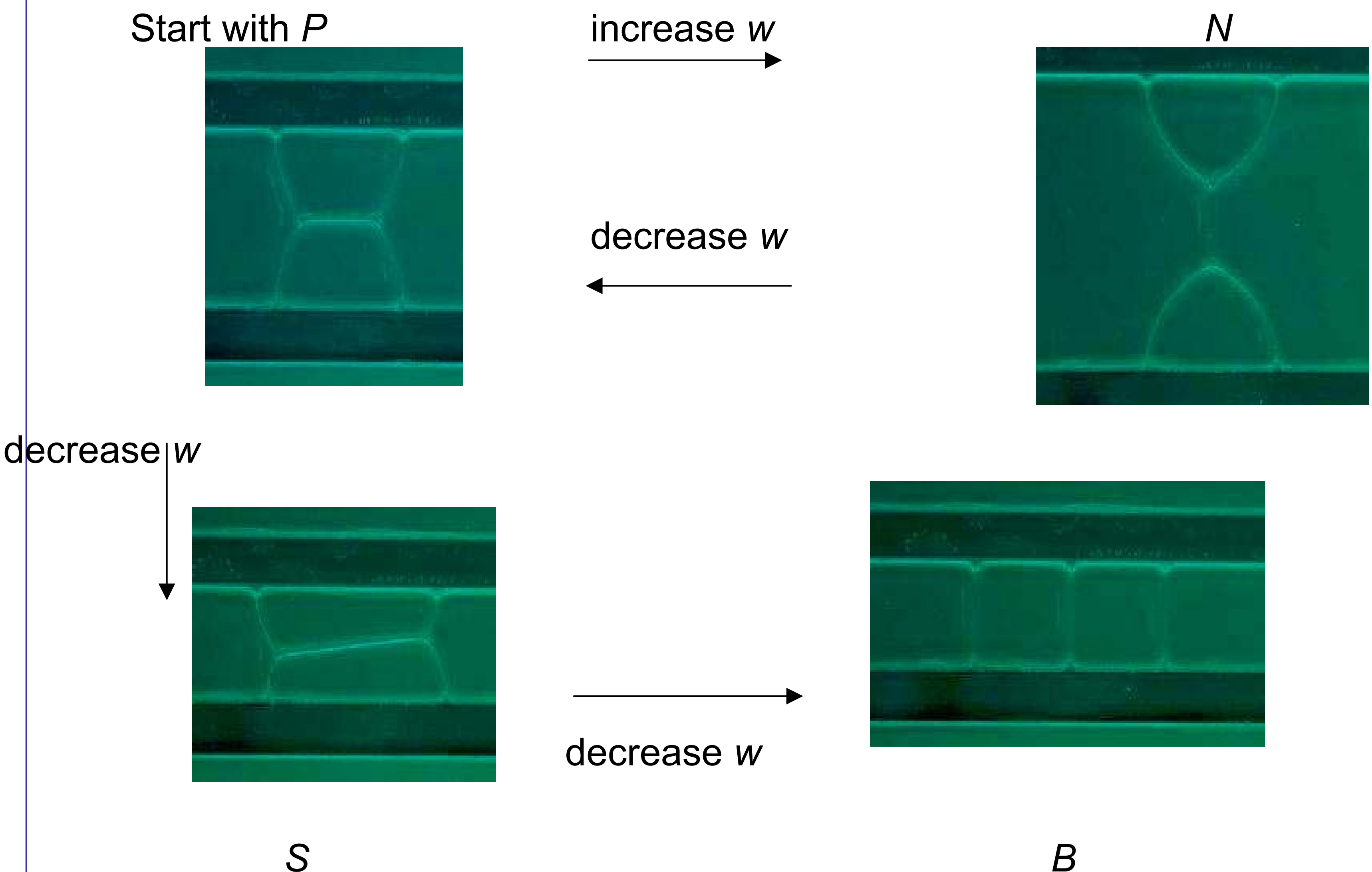
<u>Deformation of two bubbles between two bars</u>

w **= distance between two bars**

- **Increase or decrease *w***

-**Measure the critical values of *w* at which transitions occur**

-**Separations H (0.5, 1.0 and 1.5 cm) and bubble volumes V (0.5, 1 and 1.5 cm^3)**



Start with *P*
increase *w*
N
decrease *w*
decrease *w*
decrease *w*
S
B

Configuration *P* two bubbles contact each other in a film parallel to the bars

increase *w*

w_{PN} Configuration *N* or *N'* *N* – film perpendicular to the bars or the bubbles separate *N'*

decrease *w*

w_{NP} Configuration *P*

decrease *w*

w_{PS} Configuration *S* Inter-bubble film is inclined

decrease *w*

w_{SB} Configuration *B* Inter-bubble film touches the bars - bamboo

---

Measure critical *w*

Theoretical predictions

1. Dry model

⇨ **possible to calculate the ideal 2D energy for each configuration**

Calculate the critical bar spacing by calculating the value of w at which a film shrinks to zero (two vertices touch and give T1)

$$w_{SB} = 0.885\sqrt{A}$$

$$w_{PS} = 1.022\sqrt{A}$$

Fortes et al (2004)

$$w_{PN} = 3.322\sqrt{A}$$

$$w_{N'P} = 1.128\sqrt{A}$$

Vaz and Cox

Theoretical predictions

2. Wet foam

The effect of the excess liquid is to allow the bubbles to jump to an alternative configuration as the energy of the alternative configuration is lower

Critical spacing = w_{ij}

energy of configuration *i* = energy of configuration *j*

$$\begin{cases} w_{PN} = 2.586\sqrt{A} \\ w_{PN'} = 2.129\sqrt{A} \\ w_{SB} = 1.304\sqrt{A} \end{cases}$$

Predictions 1 – upper bound in traction; lower bound in compression

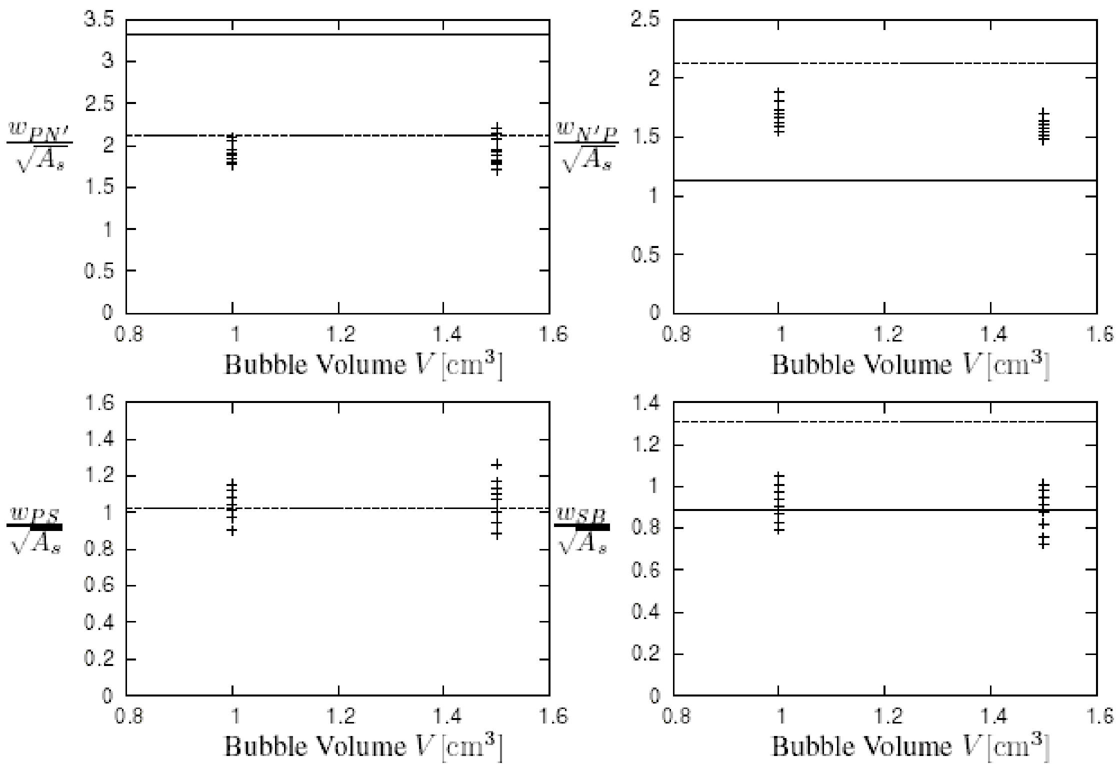
Predictions 2 – lower bound in traction; upper bound in compression

Results

LA **–bubble raft experiments**

equivalent cross section

(hemispherical bubbles)



Critical bar spacing as a function of bubble volume

(the height of the system does not play any role)

Dashed lines = equal energy predictions

Solid lines = edge shrinking to zero

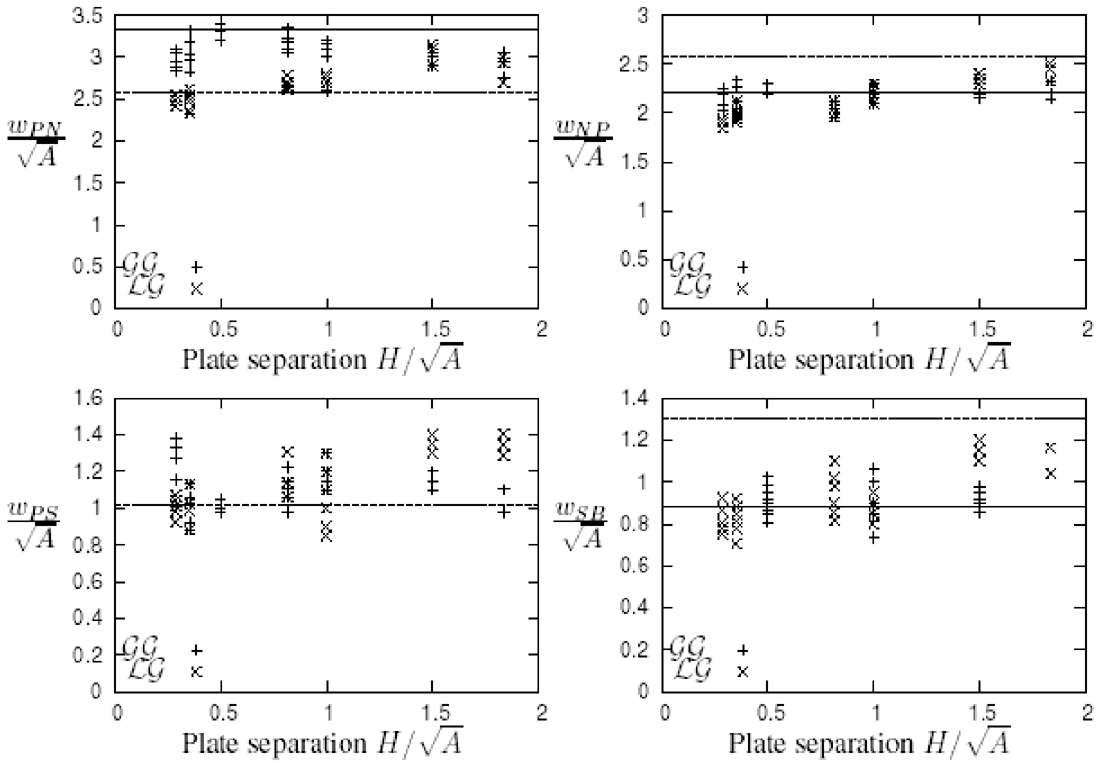
LA **system**

- the results do not change with bubble volumes
- in traction the *P-N’* transition occurs in agreement with the second prediction (uncontrollable wetness of the system)
- compression – *N’ -P* occurs before the first prediction
- *S* configuration appears where predicted
- Transition *SB* – occurs when the edge length shrinks to zero (1st prediction)

Results

LG and *GG* –

spacing *w* scaled by the square root of the bubble area A=V/H



Dashed lines = equal energy predictions
Solid lines = edge shrinking to zero

LG and GG system

- as the plate separation increases the liquid fraction of the *LG* system decreases, while the *GG* doesn't $\Rightarrow$ in the *GG* system, the critical values of *w* do not change with H
- All the *GG* results agree with the dry theory
- *LG* - in traction the *P-N* transition occurs as it is energetically favourable for low separations. As the separation increases the critical *w* approaches the first prediction
- In compression – the critical *w* increases with H
- As *H* decreases the system gets wetter, *w* decreases and is below the lower bound (2nd prediction) $\Rightarrow$ for the *LG* system the dry theory is inappropriate

<u>Discussion</u>

✓The disagreement between theoretical and experimental values are due to the 3D nature of the system

✓The glass-glass system corresponds closely to the dry theory

✓The bubble raft is the least resemblance of dry theory

✓The glass-liquid system allows the liquid fraction to change

- if $H/\sqrt{A}$ <1 – close to the wet predictions
- if $H/\sqrt{A}$ >2 – close to the dry predictions

Acknowledgments

S. Cox

K. Brakke