The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA International Atomic Energy Agency

SMR/1845-16

Conference on Structure and Dynamics in Soft Matter and Biomolecules: From Single Molecules to Ensembles

4 - 8 June 2007

Structure and dynamics in the physics of foams

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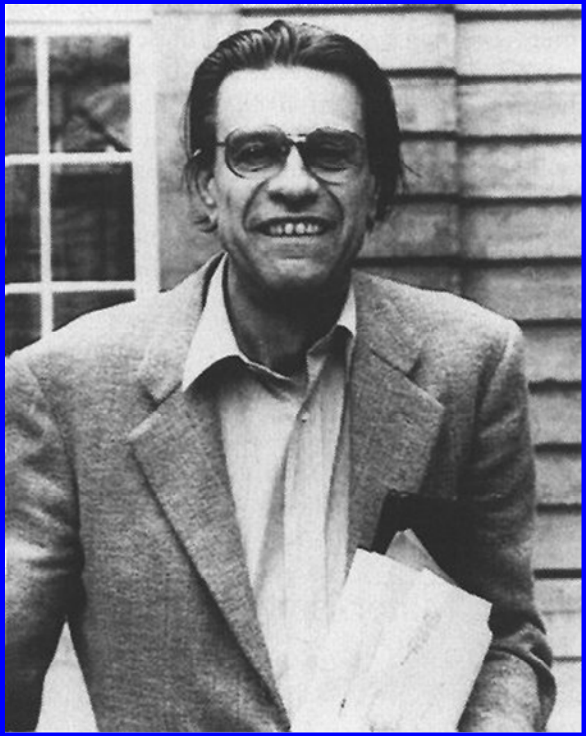
In memoriam

Pierre Gilles de Gennes

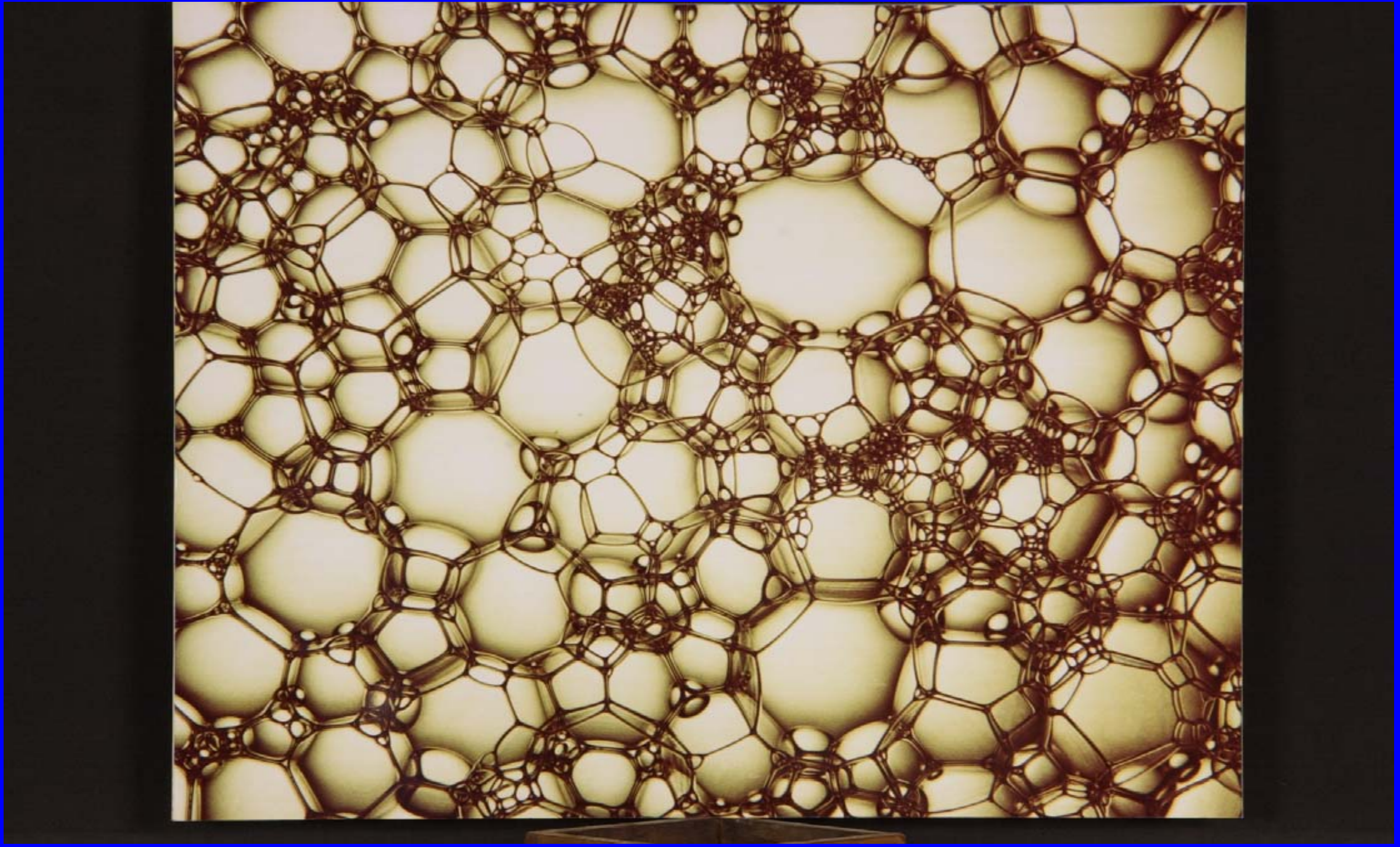
Nobel Prize Lecture

Amusons-nous. Sur la terre et sur l'onde
Malheureux qui fait son nom!
Richesse, Honneurs, faux éclat de ce monde,
Tout n'est que boules de savon.

[Let's have fun. On land and sea,
Fame brings nought but troubles,
Riches, honours, vain celebrity,
Are only soapy bubbles.]



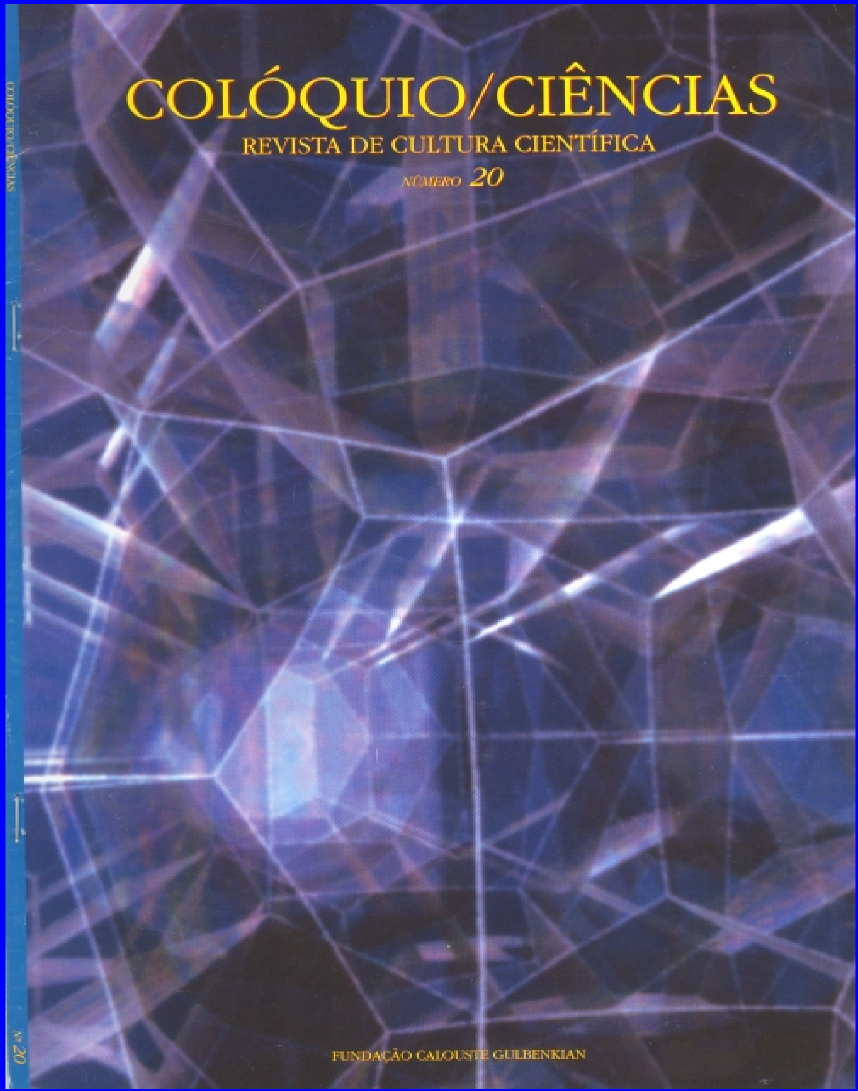
Foams (in particular, rheology**)**



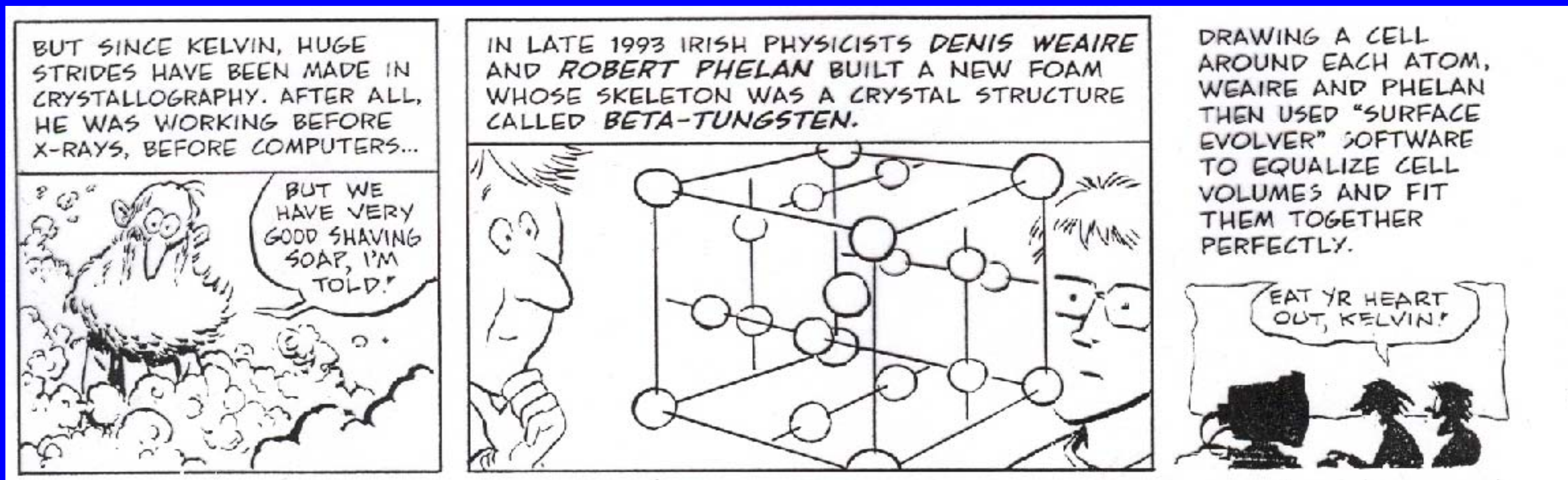
Success story: statics/quasistatics

We understand many aspects of :

- structure
- elastic behaviour, onset of plasticity
- coarsening
- drainage
- electrical/thermal conductivity
- *etc*



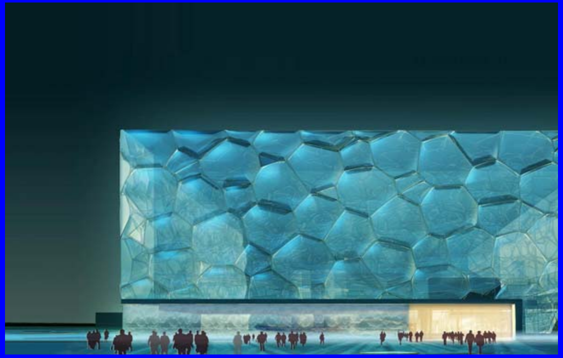
WEAIRE-PHELAN STRUCTURE

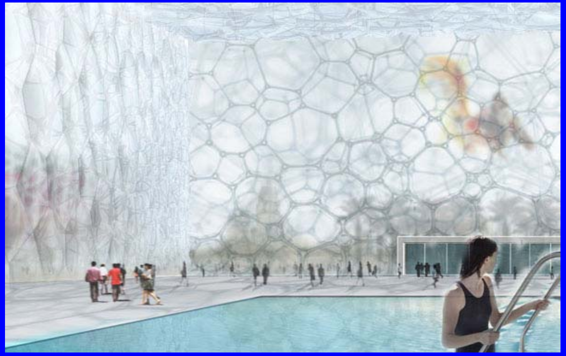


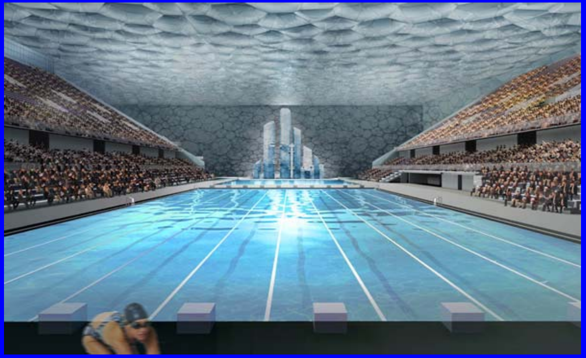
BUT SINCE KELVIN, HUGE STRIDES HAVE BEEN MADE IN CRYSTALLOGRAPHY. AFTER ALL, HE WAS WORKING BEFORE X-RAYS, BEFORE COMPUTERS...
BUT WE HAVE VERY GOOD SHAVING SOAP, I'M TOLD!
IN LATE 1993 IRISH PHYSICISTS *DENIS WEAIRE* AND *ROBERT PHELAN* BUILT A NEW FOAM WHOSE SKELETON WAS A CRYSTAL STRUCTURE CALLED *BETA-TUNGSTEN.*
DRAWING A CELL AROUND EACH ATOM, WEAIRE AND PHELAN THEN USED "SURFACE EVOLVER" SOFTWARE TO EQUALIZE CELL VOLUMES AND FIT THEM TOGETHER PERFECTLY.
EAT YR HEART OUT, KELVIN!

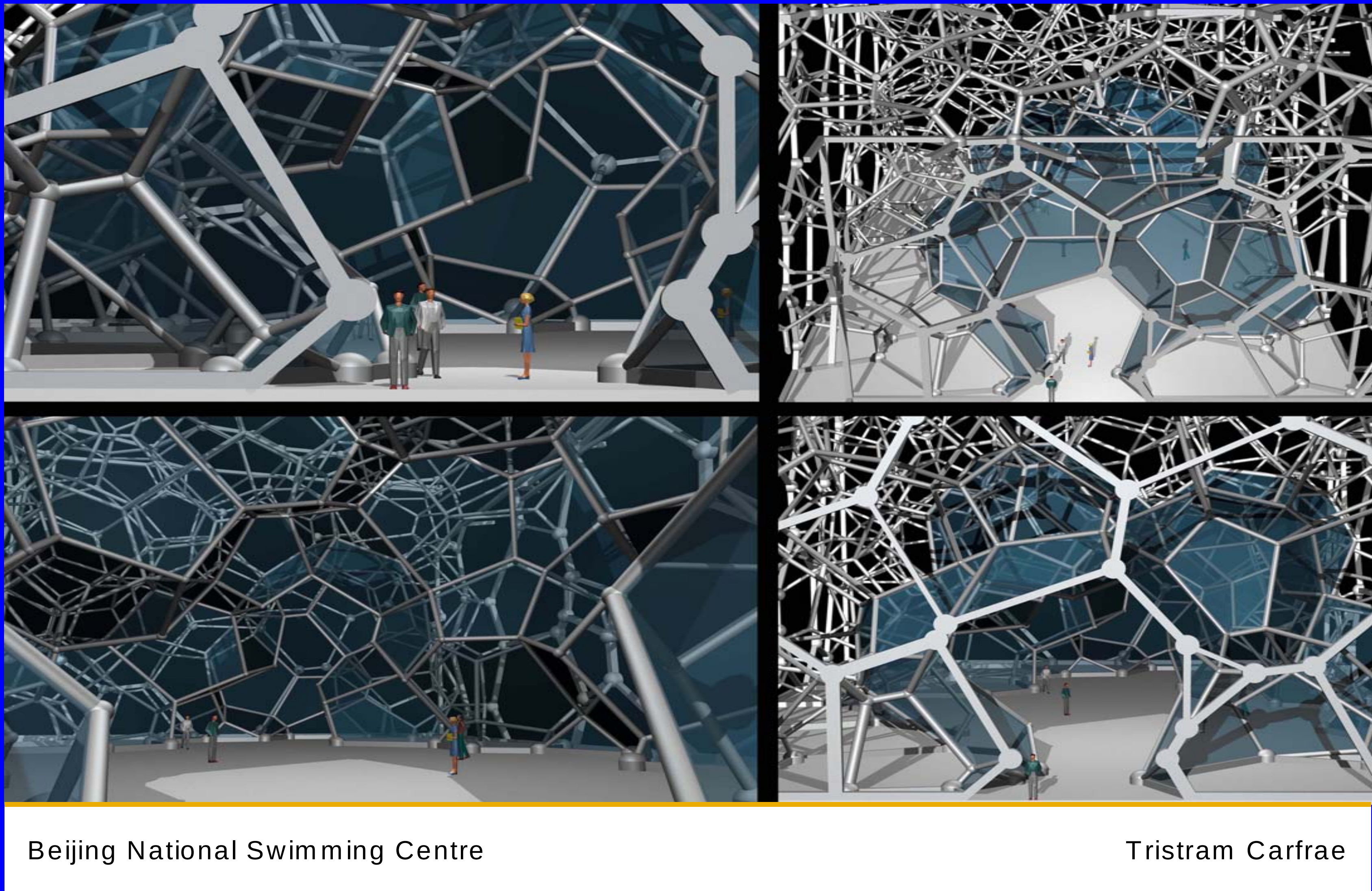
The Water Cube

Arup’s winning design for the 2008 Beijing Olympics, National Swimming Centre





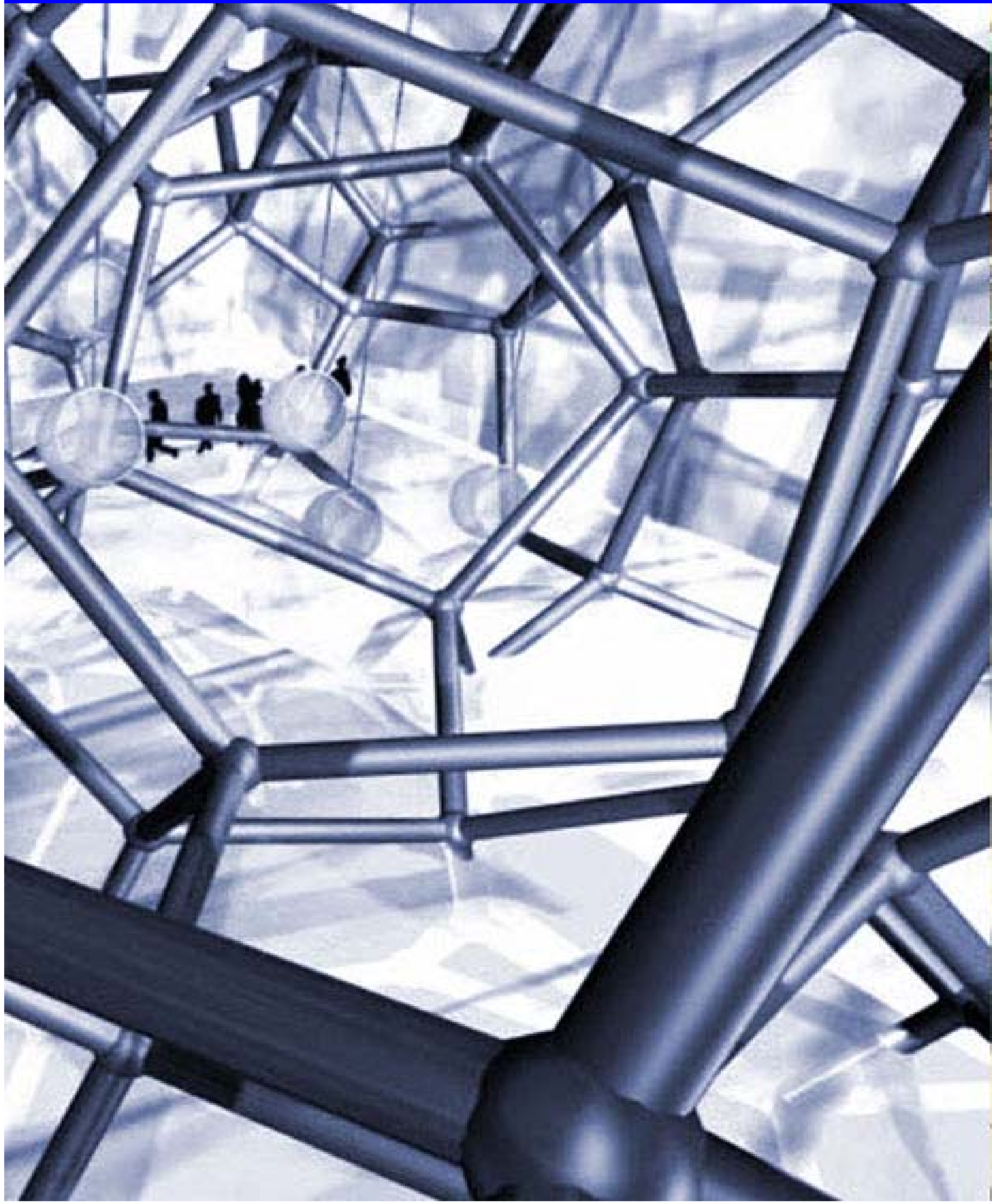


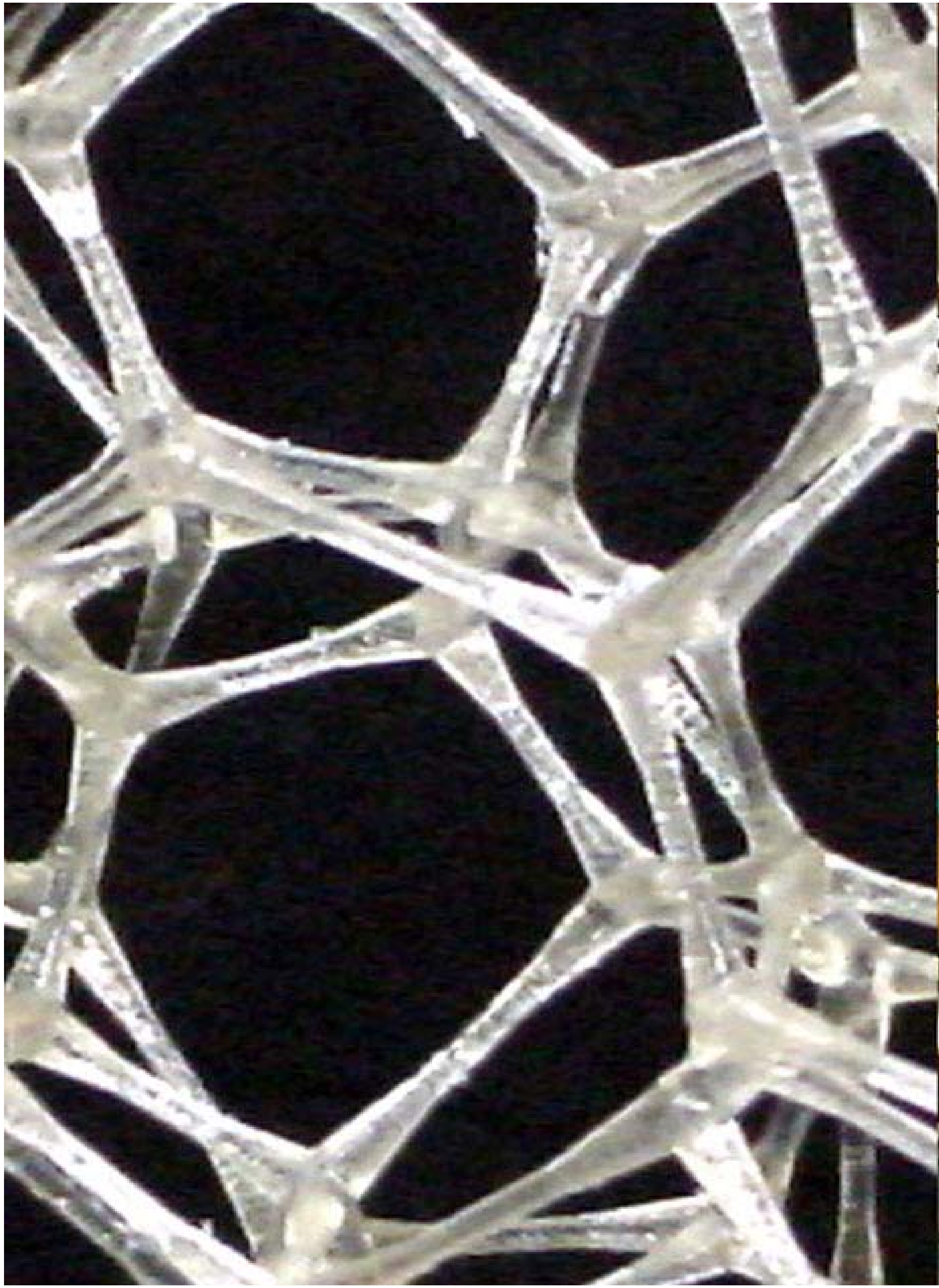


6500 tonnes of steel

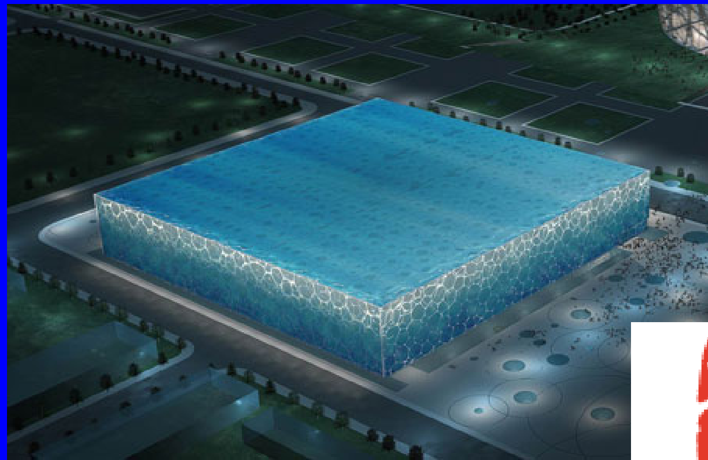
Steel beams would stretch for 90kms

4,000 bubbles !

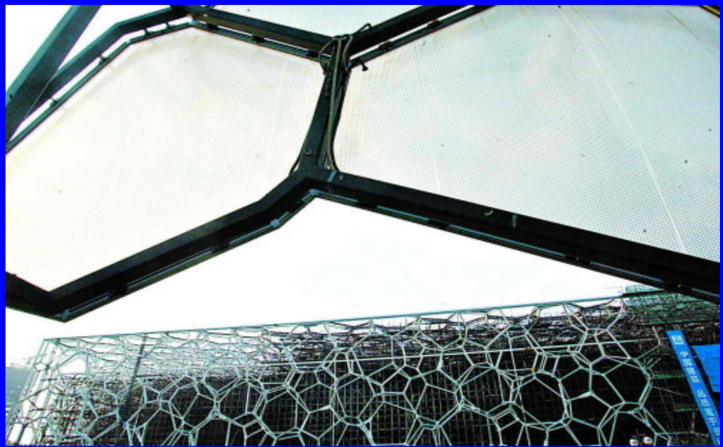



It even looks like it is supposed to do…



Beijing 2008



http://www.flickr.com/search/?q=watercube&m=text

VIDEO CLIP

April 2007 Beijing Olympic buildings

http.//educatedearth.net/video.php?id=3152

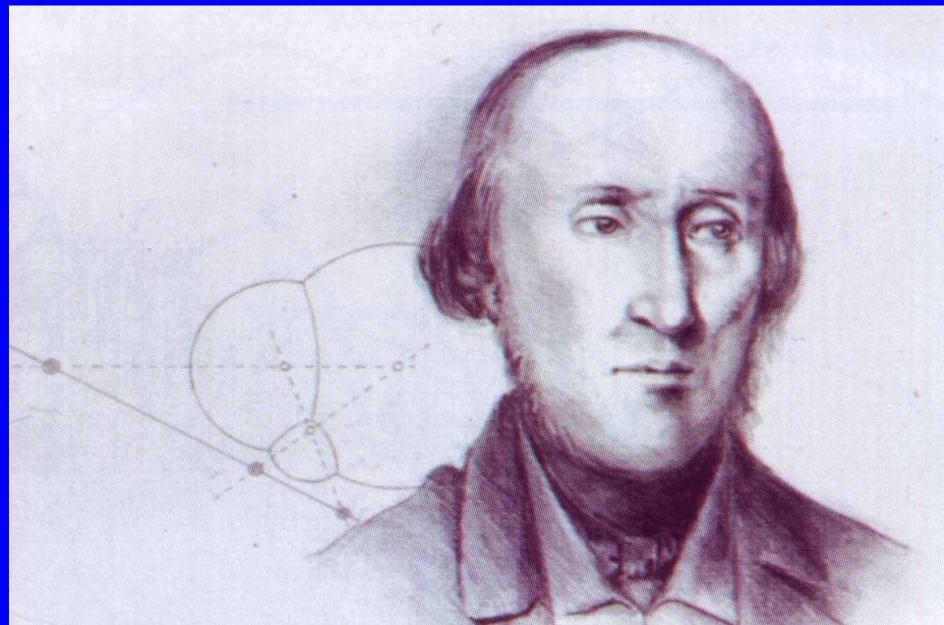
Joseph Plateau

Blind experimentalist

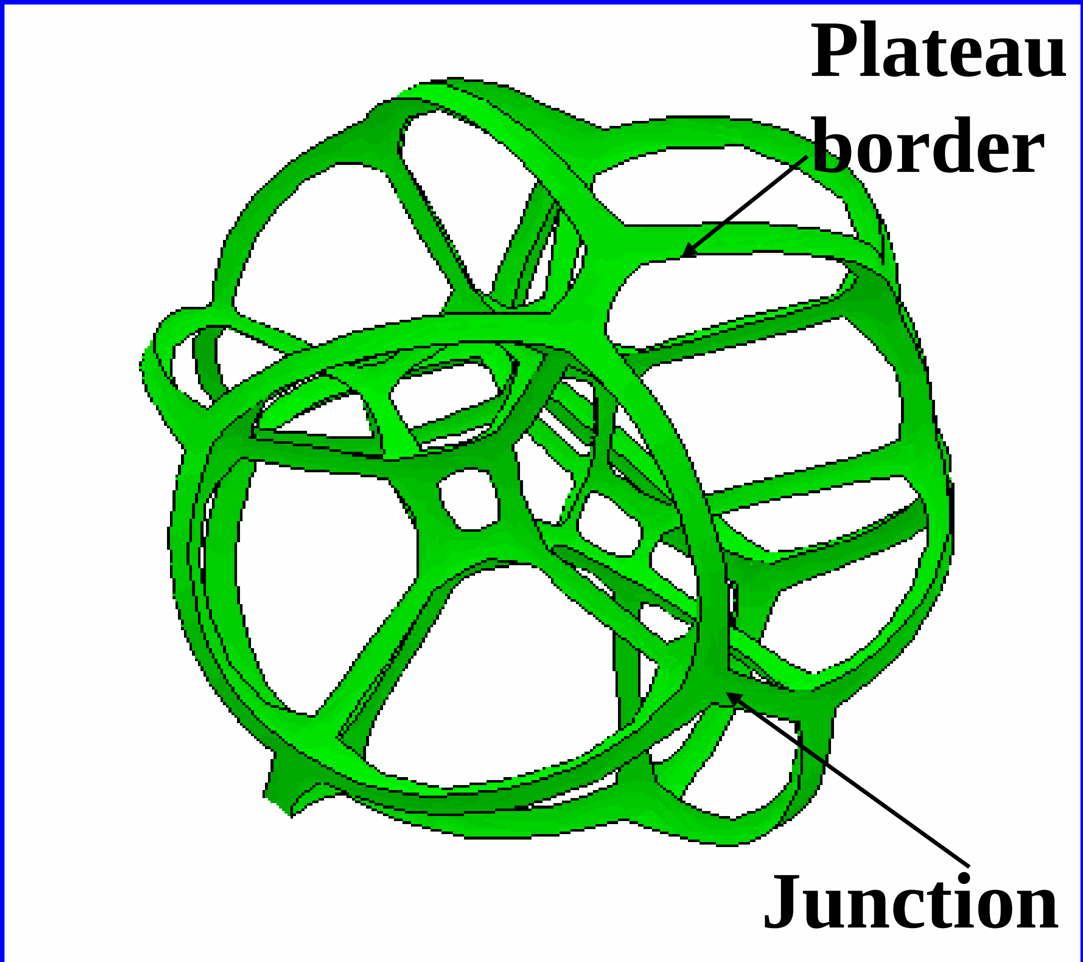
Classic text 1873

Rules of equilibrium

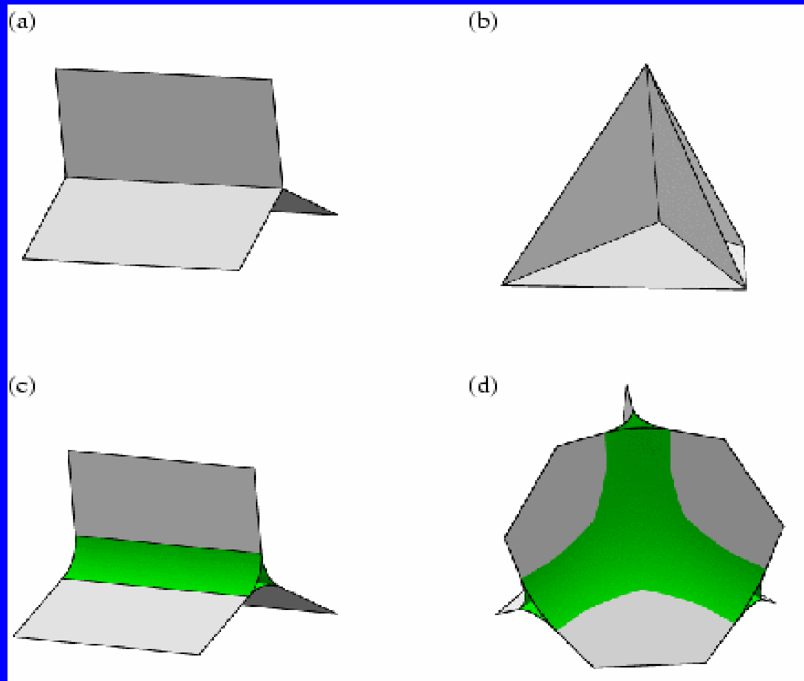
Wire frame demos



Elements of the foam structure



Dry Foam

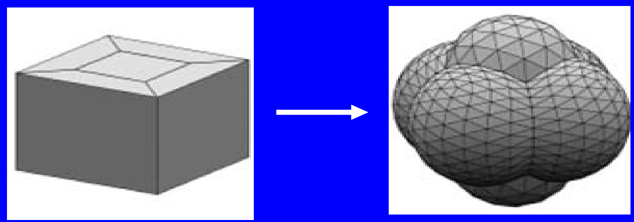


Wet Foam

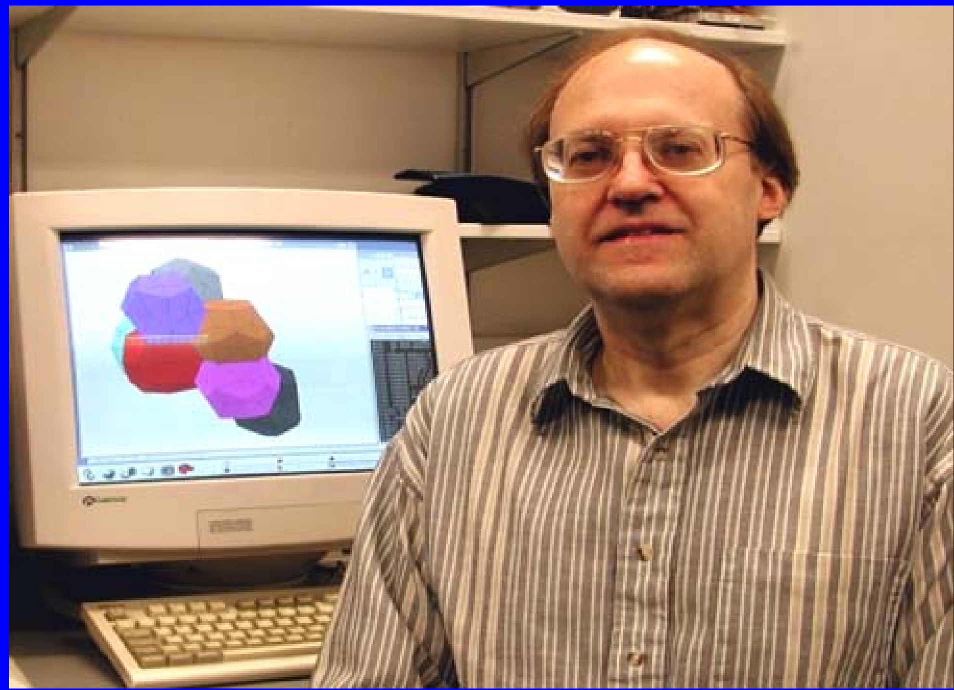
Ken Brakke

Mathematician

Surface Evolver

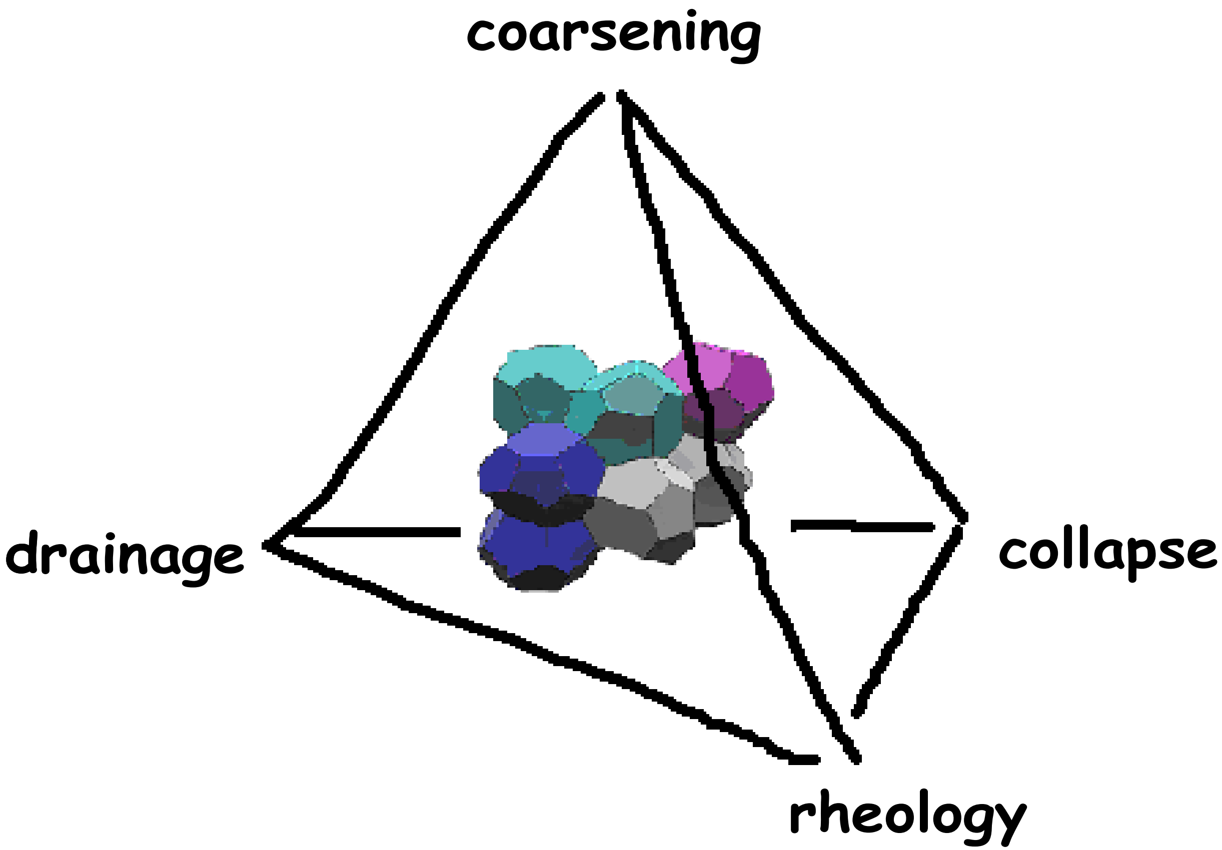


http://www.susqu.edu/facstaff/b/brakke/



John Sullivan, Andy Kraynik

The evolver is a spectacular example of the effects of a gift to science which advances a whole field. Alan L. Mackay


coarsening
drainage
collapse
rheology

Cyril Stanley Smith

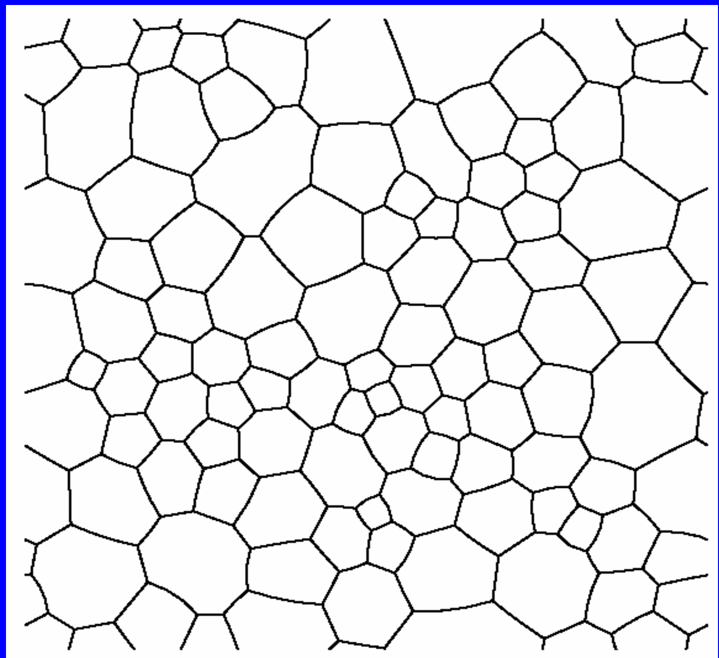
Metallurgist

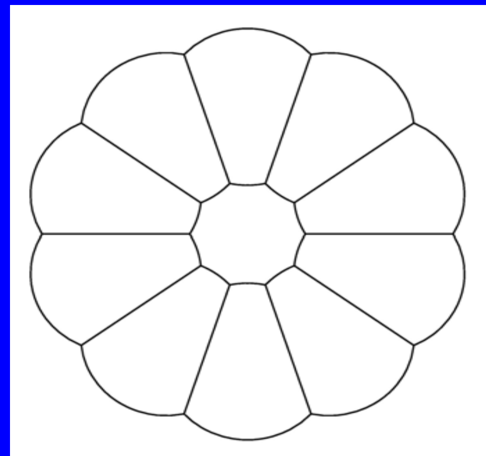
2D soap froth

Model for grain growth

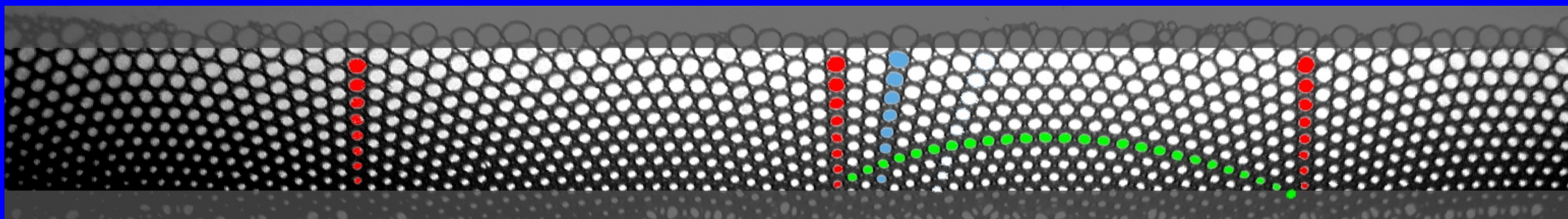
Inspiring influence!

Two – dimensional foams





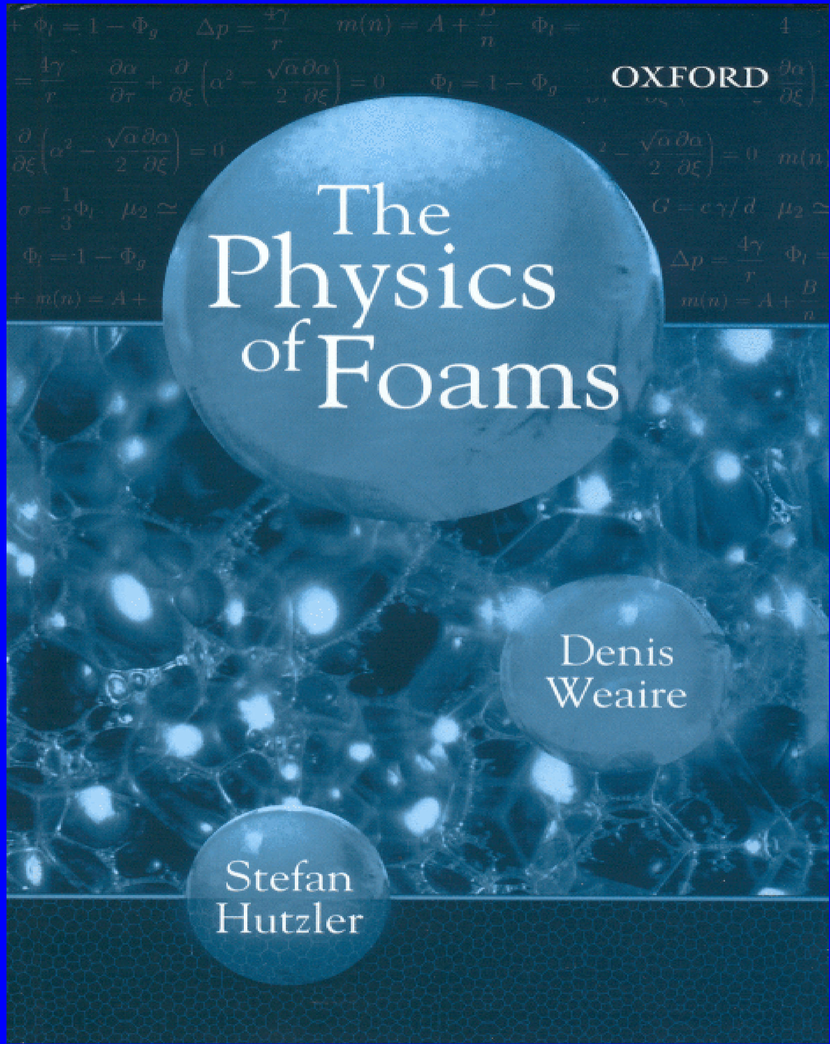
Gravity's rainbow



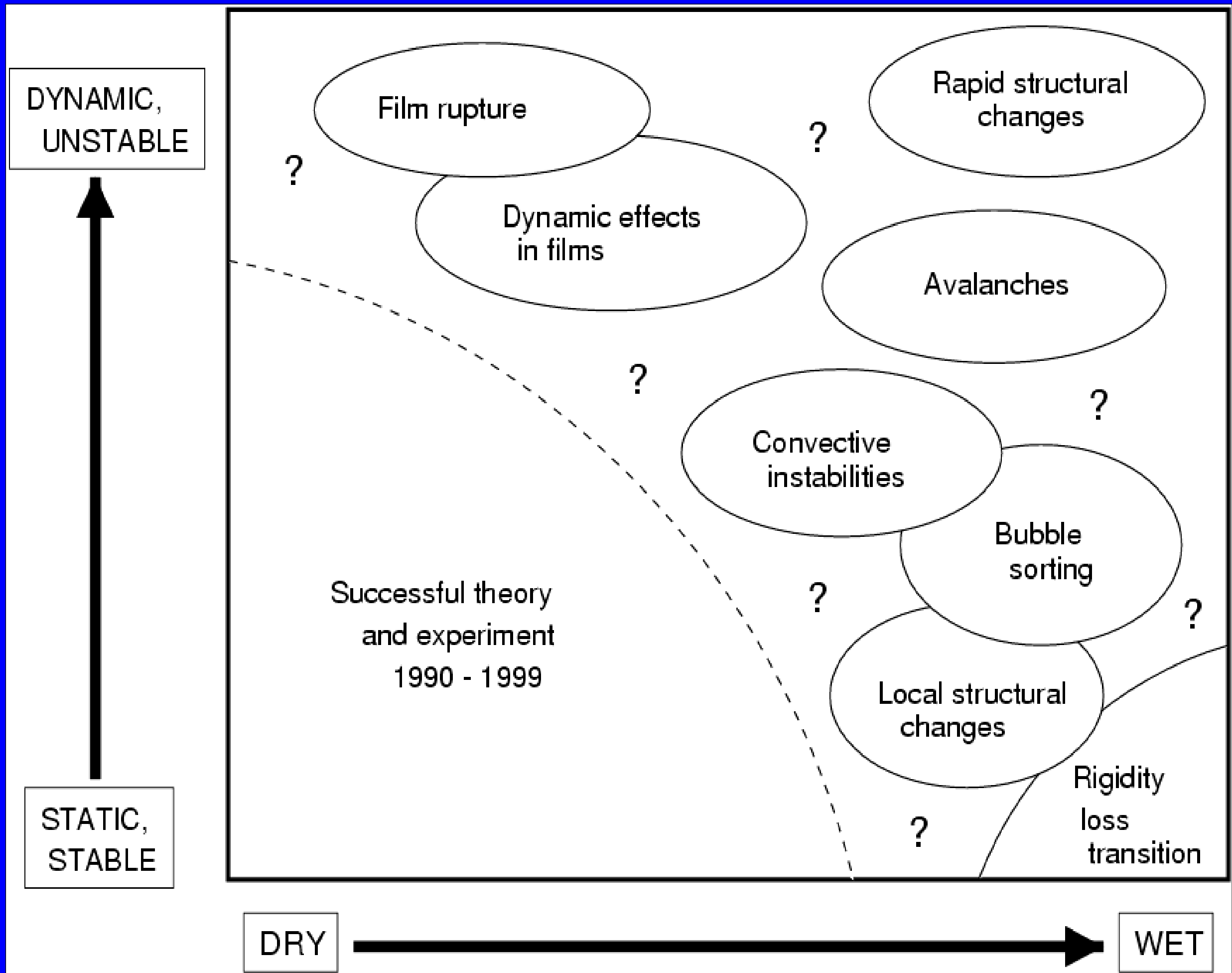
From statics to dynamics…

Statics and quasistatics: structure, elasticity, coarsening

Dynamics: drainage and rheology



New frontiers in foams



The Challenge to Theory and Simulation

? Local dynamics of bulk liquid, surfaces and gases — Chemistry, surface chemistry

? Dynamics of structured elements: films, Plateau borders and junctions — Physics, local rheology

? Continuum description of bulk properties: drainage, **rheology** (coarsening, collapse) — *RHEOLOGY*


IF ONLY EVERYTHING
FLOWED SO FREEL
Dublin Bus
Serving the Entire Community
TAXI
30110

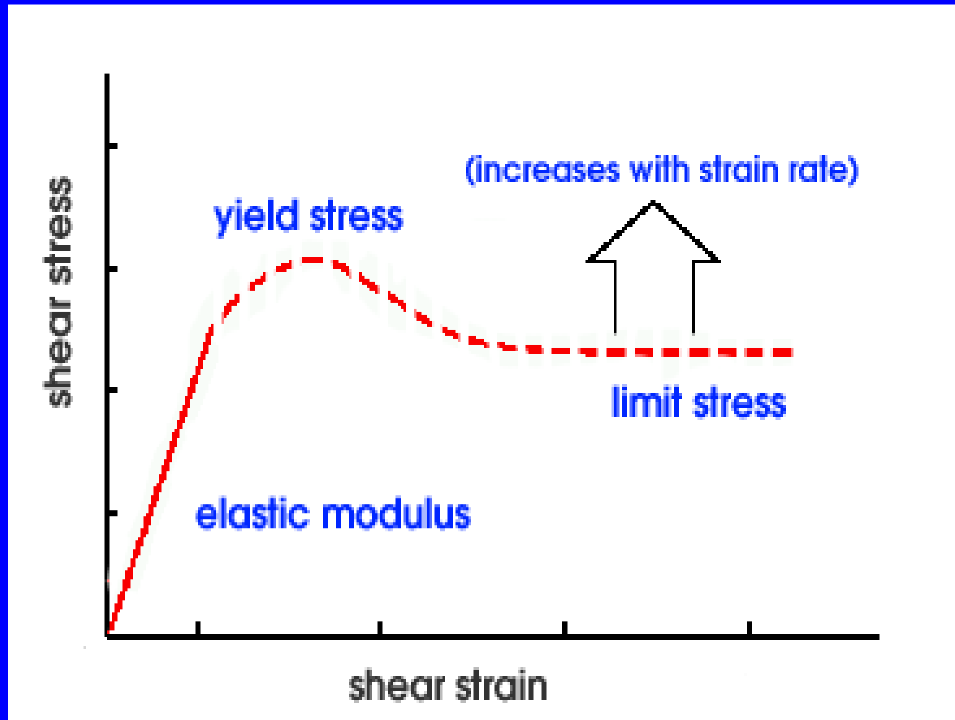
Rheology with yield stress

Steady shear

Yield stress=limit stress?

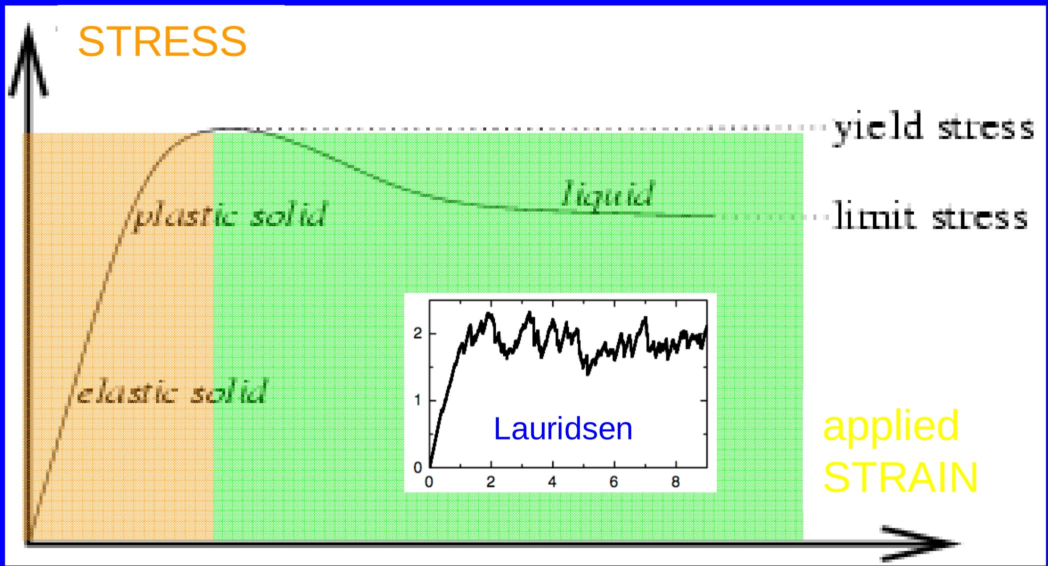
Stress = limit stress + X

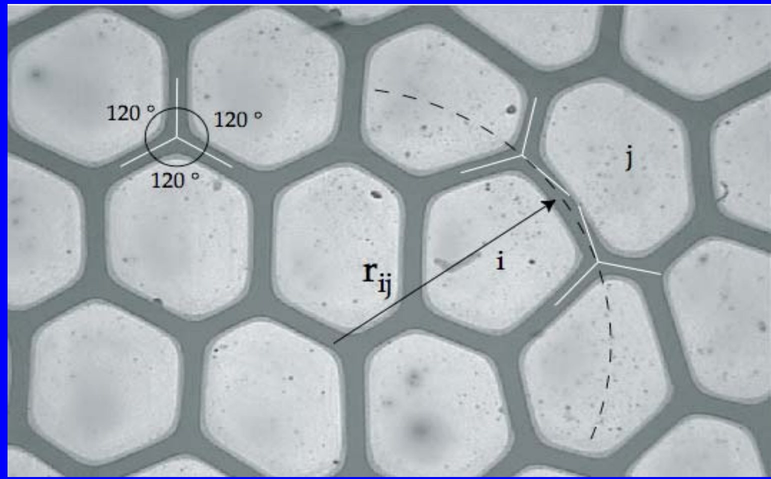
$X \sim (\text{strain rate})^n$, n = ?



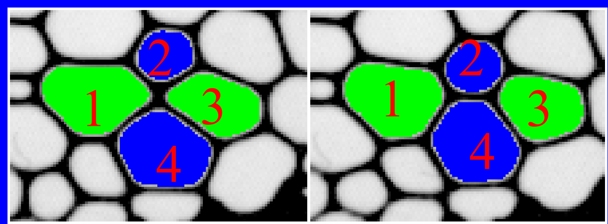
(quasi) 2D foams as a model system for foam rheology

- simpler and easier than 3D foams!
- same generic mechanical properties
  - elastic at small strain
  - flow at large strain (hysteretic!)
  - funeous?





T1 events: plasticity

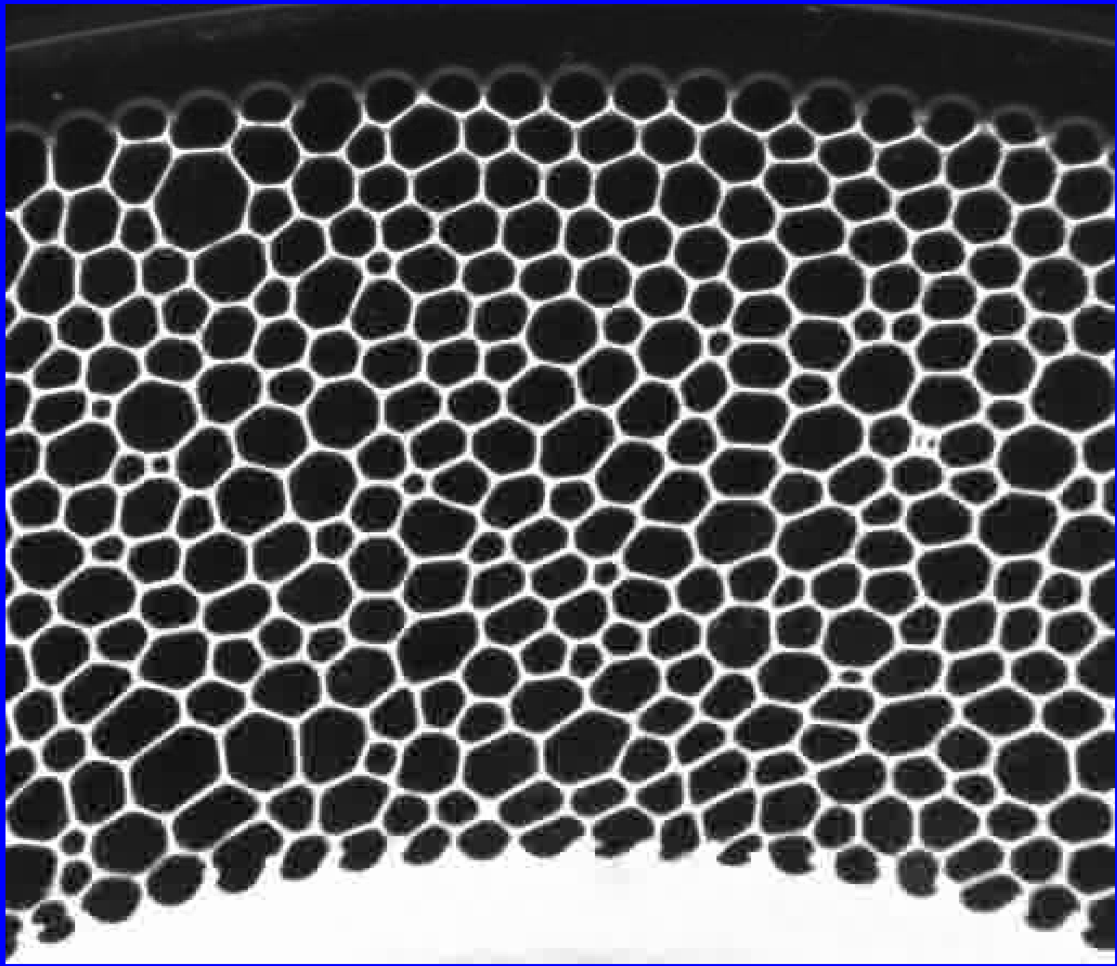


The Experiment of Debregeas

Between glass plates

Localisation

G.Debregeas *et al*,
Physical Review Letters
8717,8305 (2001)



A 2d effect: wall drag

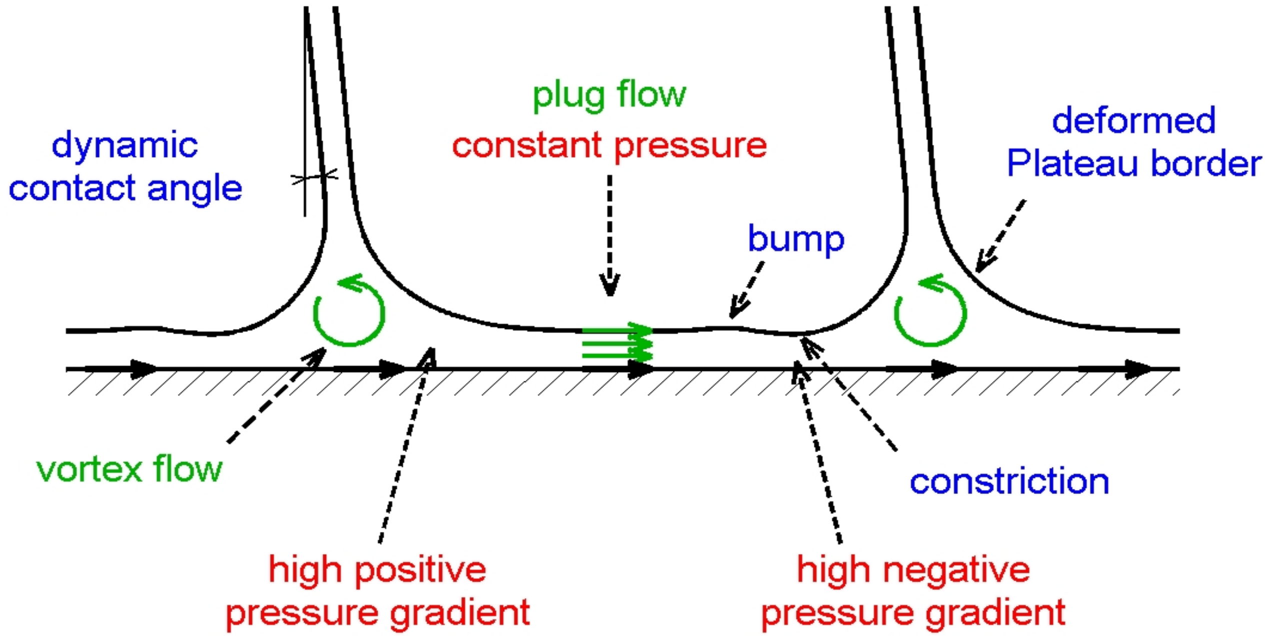
$$F \sim v^n$$

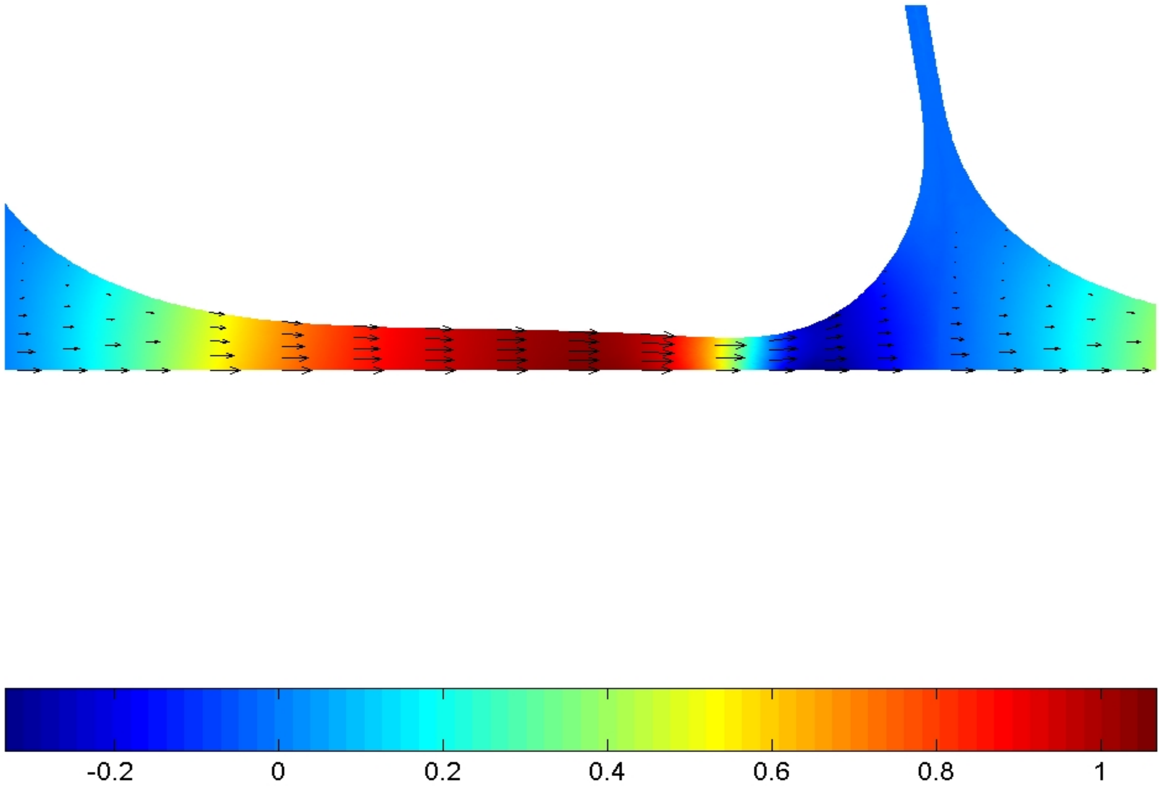
Mobile Surface

$n = 2/3$ Bretherton

Immobile Surface

$n = 1/2$ Denkov *et al.*


plug flow
constant pressure
dynamic
contact angle
deformed
Plateau border
bump
vortex flow
constriction
high positive
pressure gradient
high negative
pressure gradient



-0.2
0
0.2
0.4
0.6
0.8
1

A continuum model?

Detailed quasistatic simulations have shown localisation (shear banding) but with some anomalous features.

Why not attempt a continuum description?

Four key ingredients:

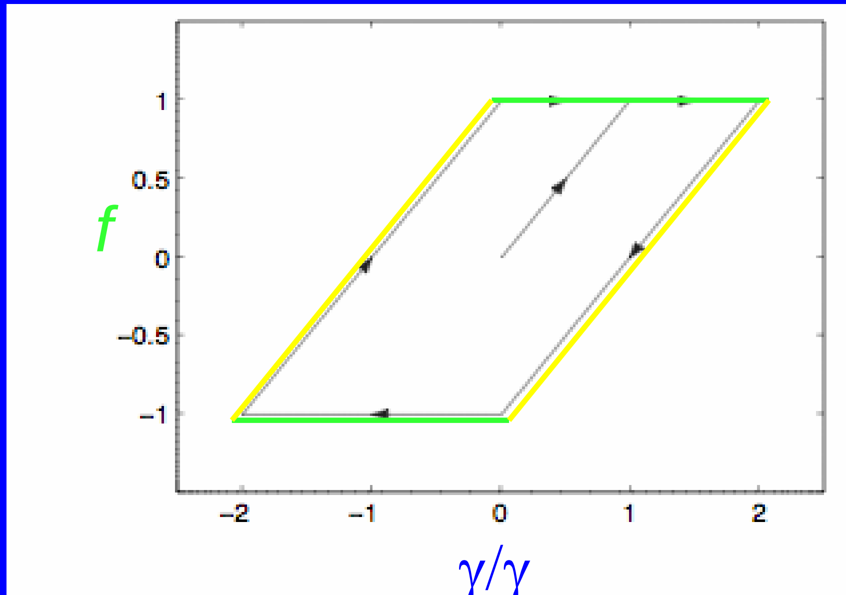
Bingham-like constitutive equation:

$$\sigma = \sigma_0 f(\gamma/\gamma_0) + \eta \dot{\gamma}$$

Elastic Plastic viscous

$f(x) = \tanh(x)$

hysteretic cycle



(linear) Viscous drag:

$$F = \beta v$$

σ_0 *yield stress*

η *Bingham viscosity*

β *viscous drag coefficient*

Scaling parameters of the fluid:

characteristic length:

$$L_0 = \sqrt{\frac{\eta}{\beta}}$$

characteristic velocity:

$$V_0 = \frac{\sigma_Y}{\sqrt{\eta\beta}}$$

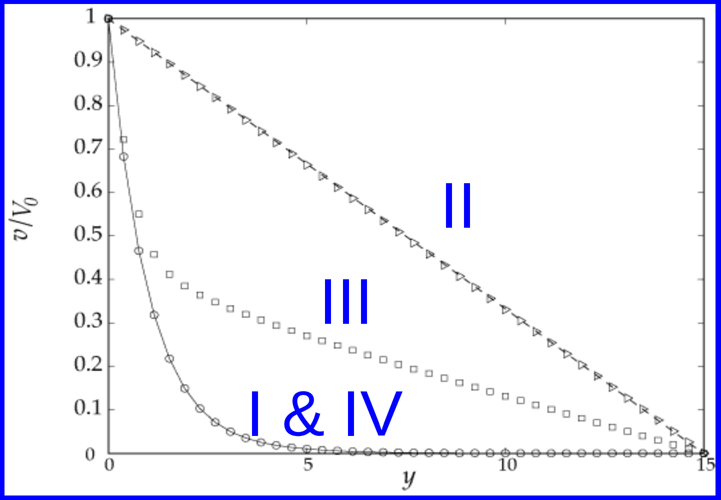
Hence a simple continuum model for quasi 2D foams

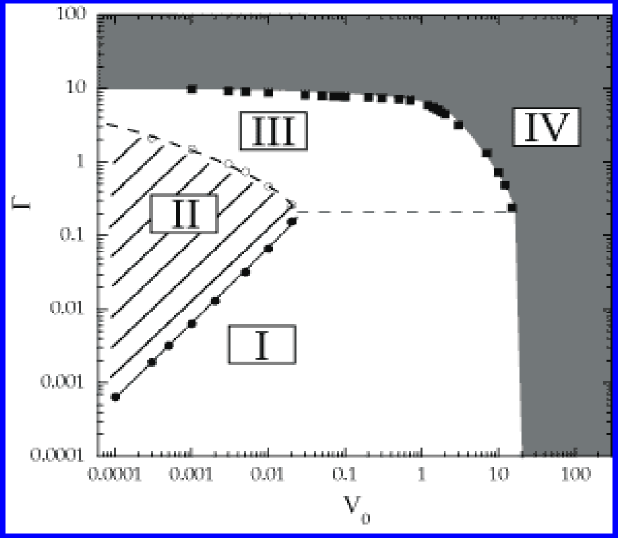
- simple constitutive equation

$$\sigma = \sigma_y \tanh\gamma + \eta\dot{\gamma}$$

- adding viscous drag for quasi 2D foams:

$$\mathrm{div}\,\sigma = \beta v$$

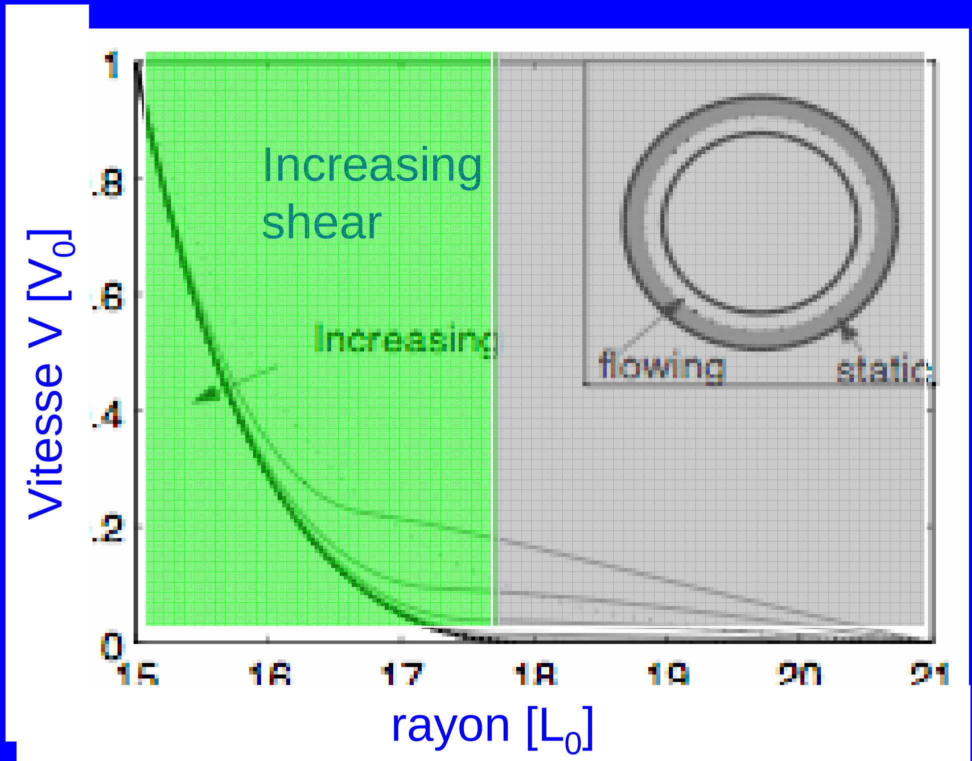


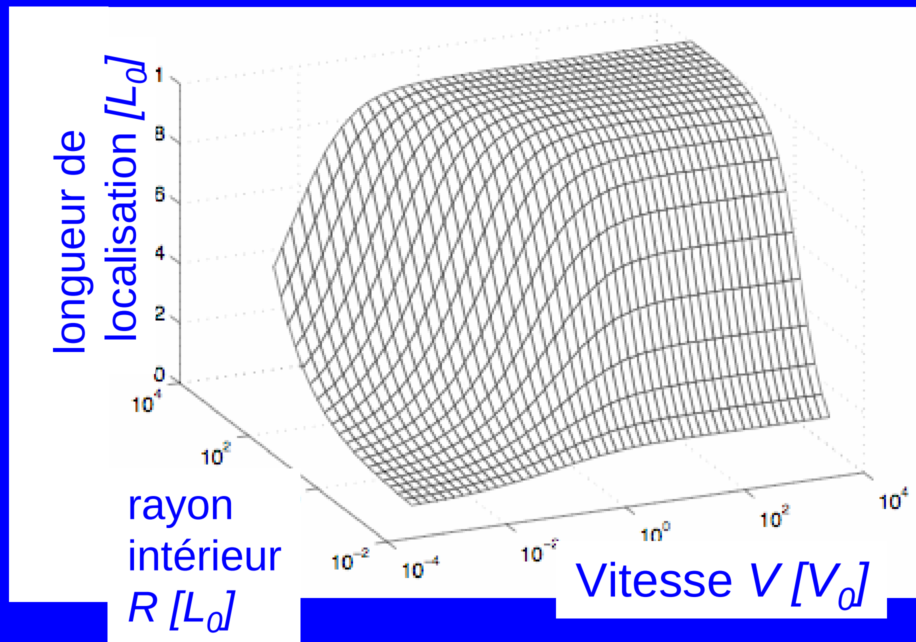


D. Weaire, E. Janiaud, S. Hutzler, PRL

Couette geometry: inner rotating boundary

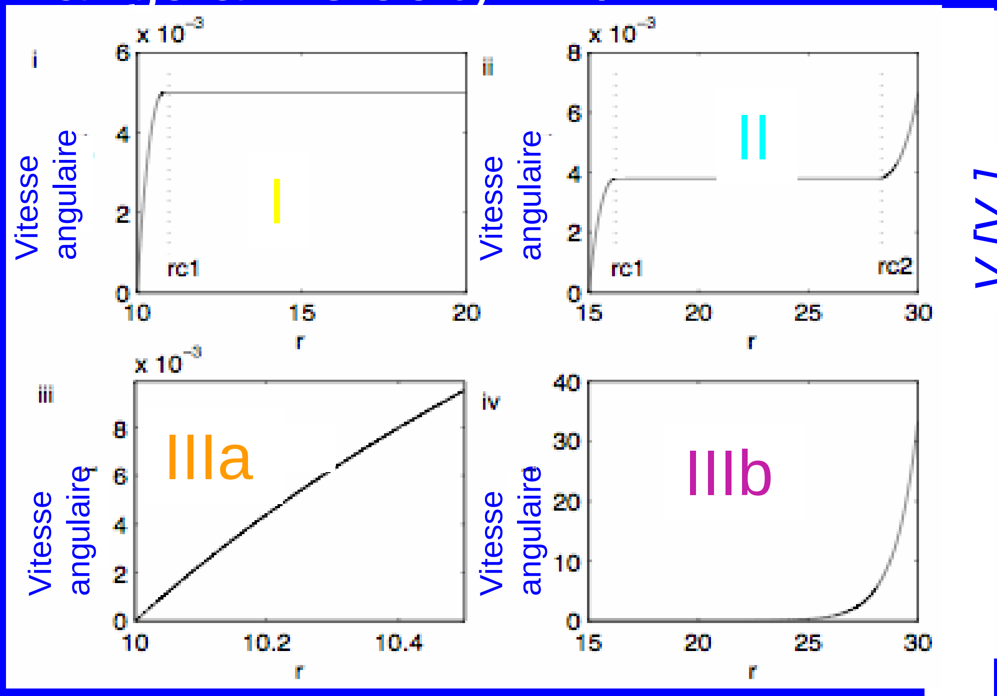
Localisation length varies

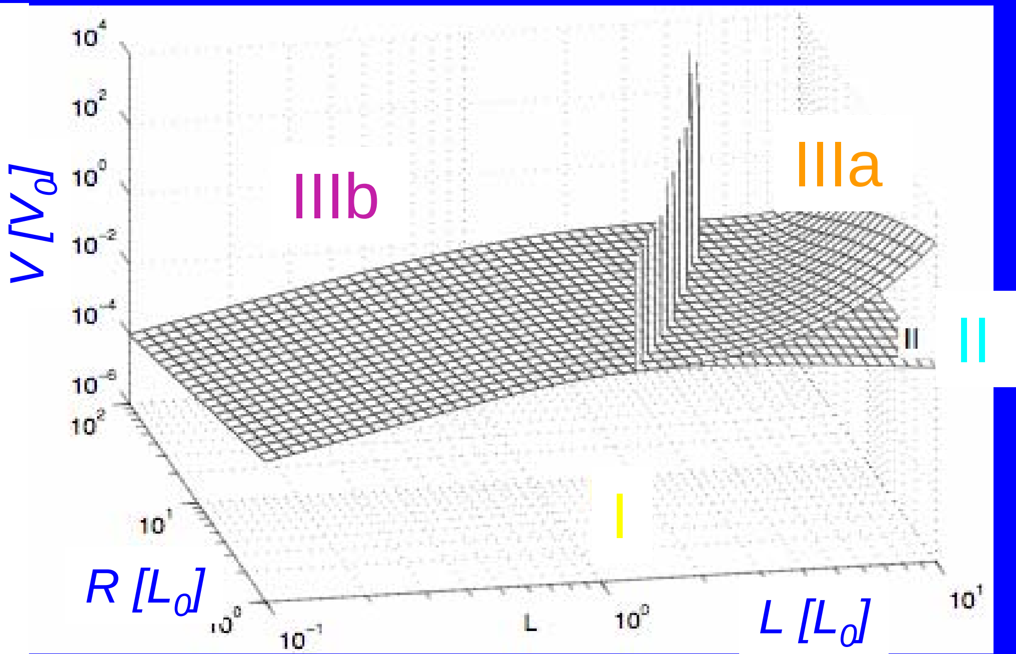




Outer moving boundary

angular velocity = *v/r*

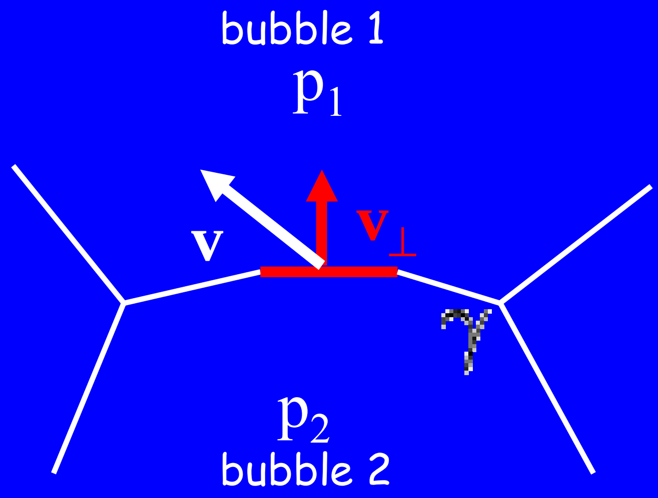




I et IIIa experimentaly observed (Lauridsen prl 2004 &2002)

IIIa et IIIb correspond to the straight edge case

Dynamics with drag?



P_i - pressure in bubble I
γ - surface tension
c - curvature
λ - drag coefficient
$v_\perp$ - normal velocity

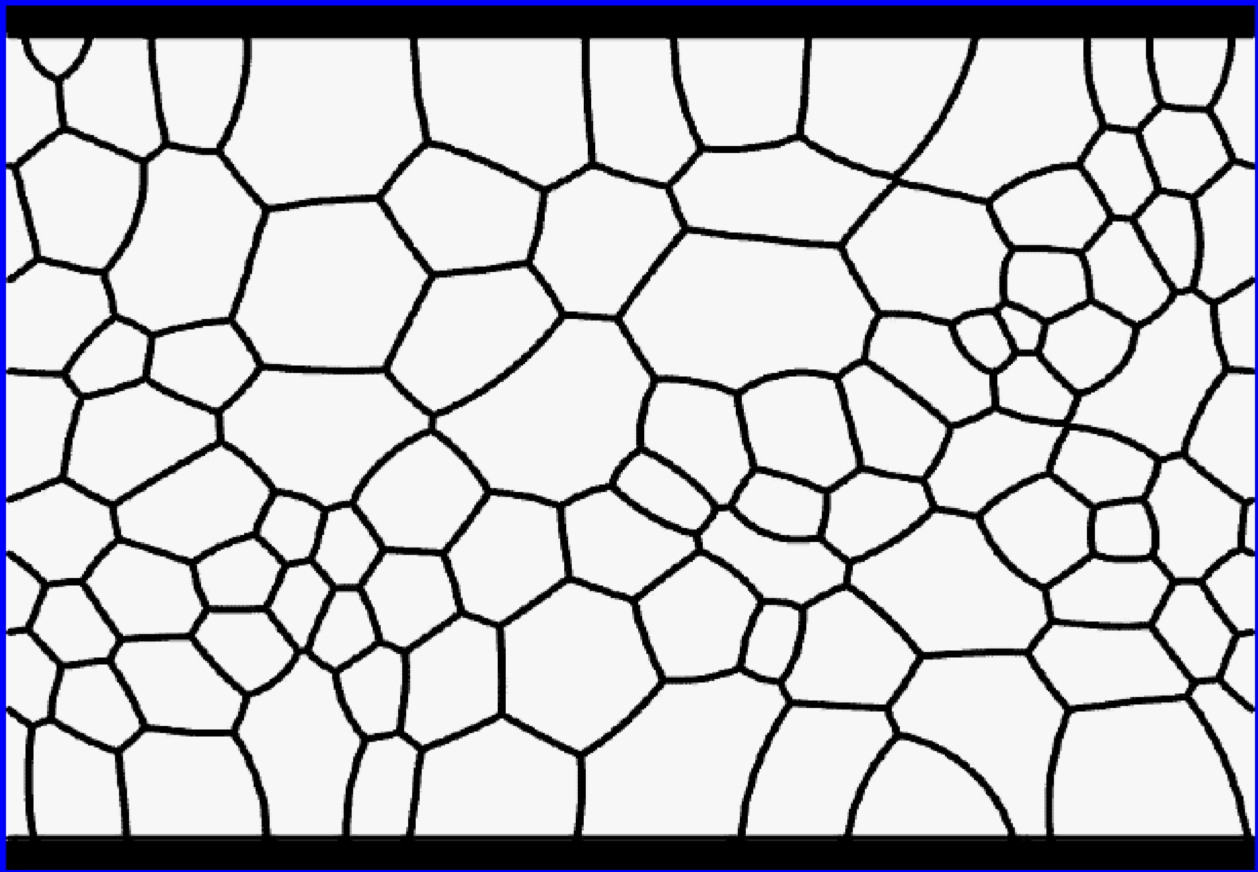
Laplace law:

$$P_1 - P_2 = \gamma c$$

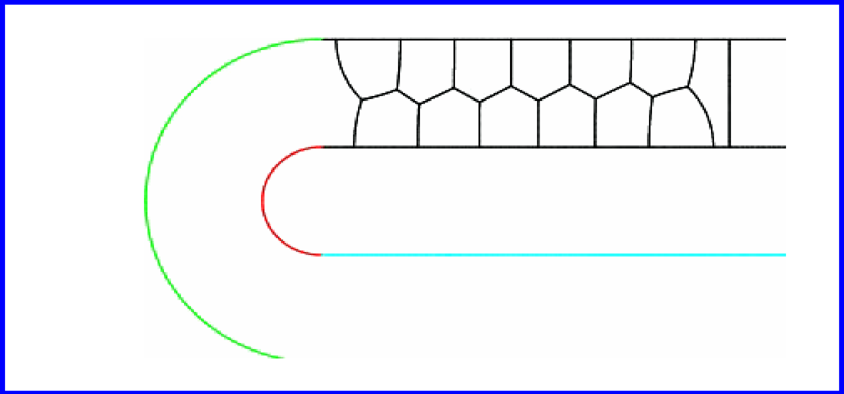
Viscous froth:

$$P_1 - P_2 = \gamma c - \lambda v_\perp$$

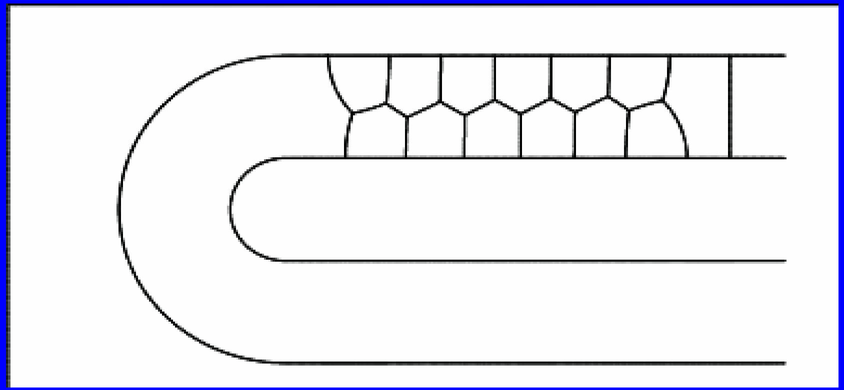
Viscous Froth 2



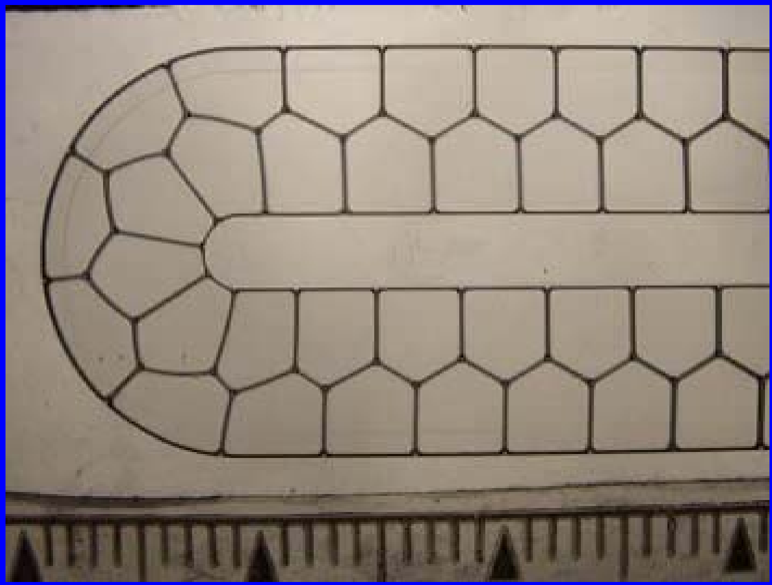
Geometric effects in channels



quasi – static --> no T1

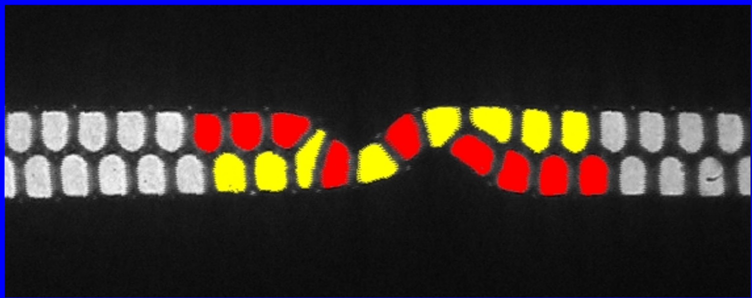


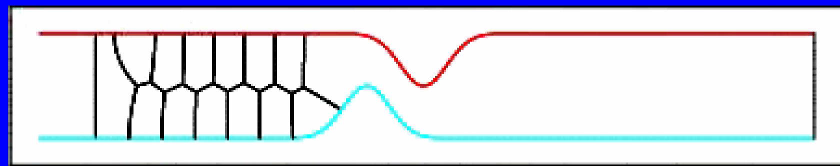
viscous froth --> T1

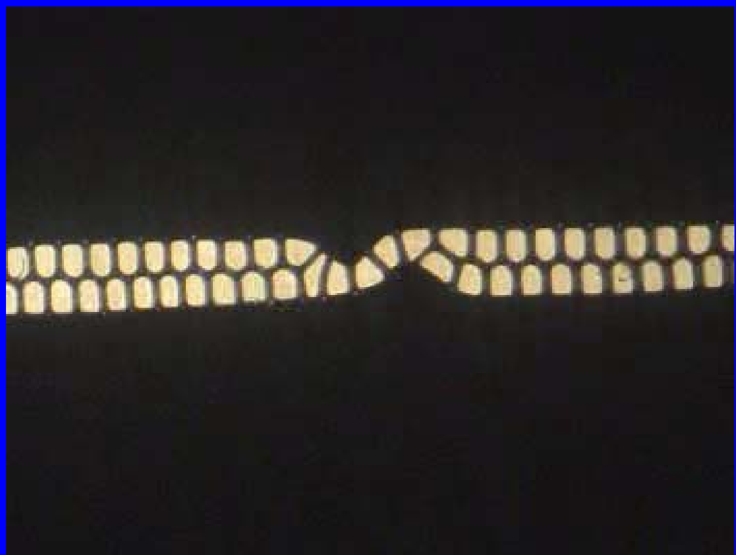


Experiment
increase velocity

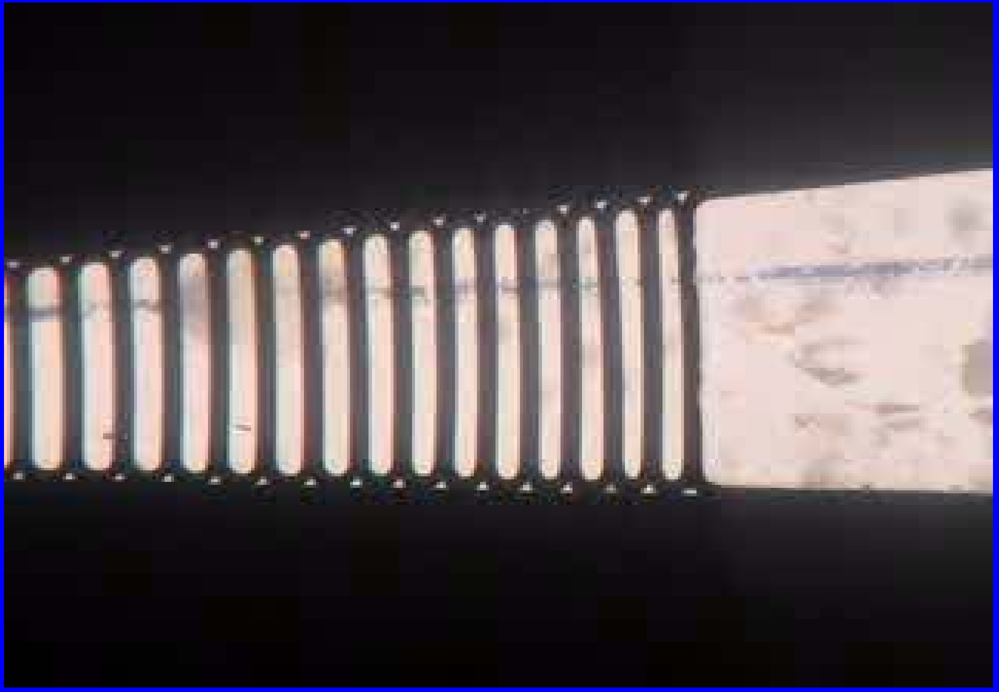
The Flipper







The Zipper



The Y-junction