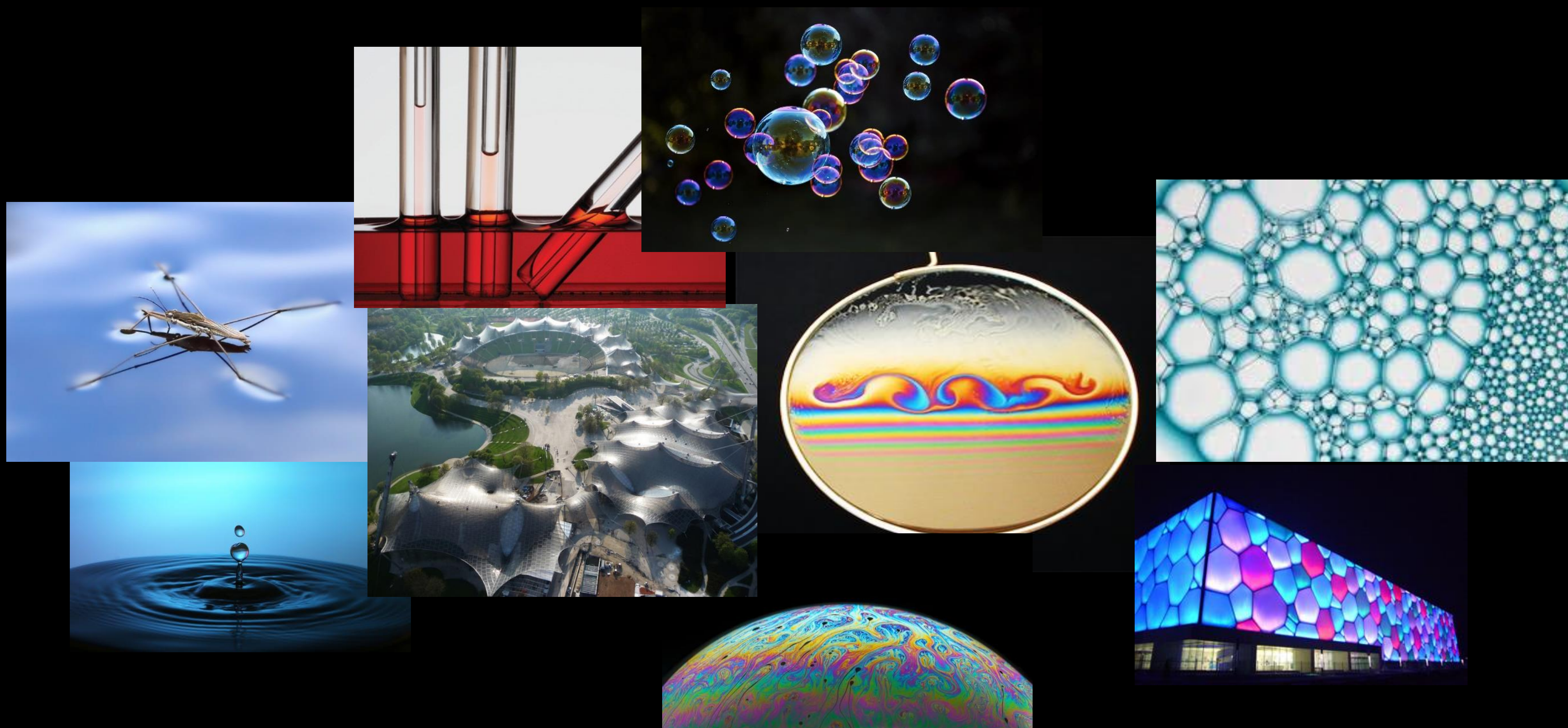
Bulles pour les nuls III :
Et pour la fin … une petite mousse

Thierry Charitat &
Wiebke Drenckhan

Bulles pour les nuls :
la physique des interfaces

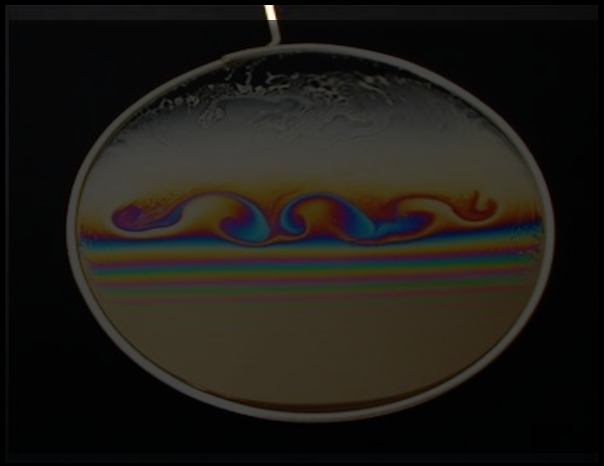
Interfaces ⟶ **Films** ⟶ **Bulles** ⟶ **Mousses & émulsions**



D’où viennent les formes et les couleurs ? Comment les décrire ?
A quoi cela peut-il servir ?

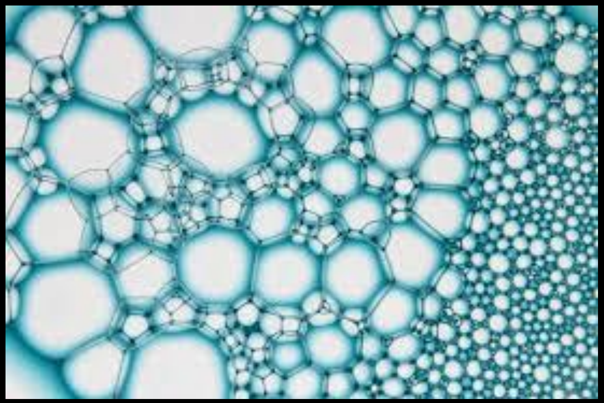
Mardi 30/05

Marcher sur l'eau



Mardi 07/06

Comment se faire un film… moléculaire



Mardi 14/06

Et pour finir …
une petite mousse

Thierry CHARITAT
Professeur de Physique à l'Université de Strasbourg
Institut Charles Sadron

Wiebke DRENCKHAN
Directrice de Recherche en physique au CNRS
Institut Charles Sadron

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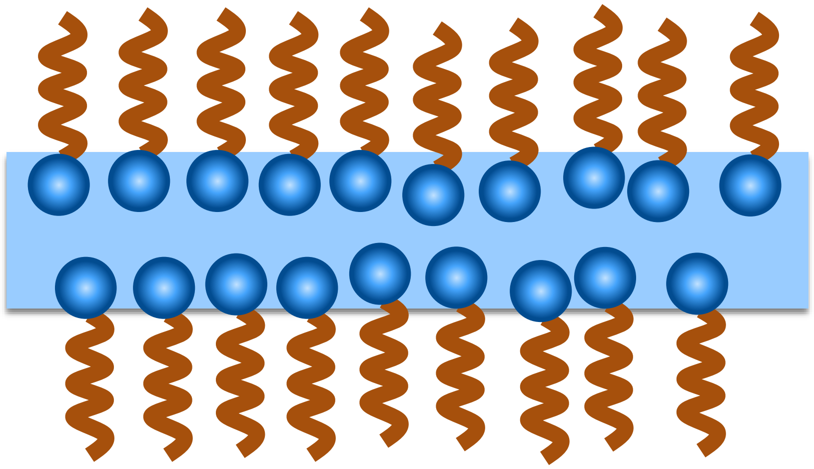
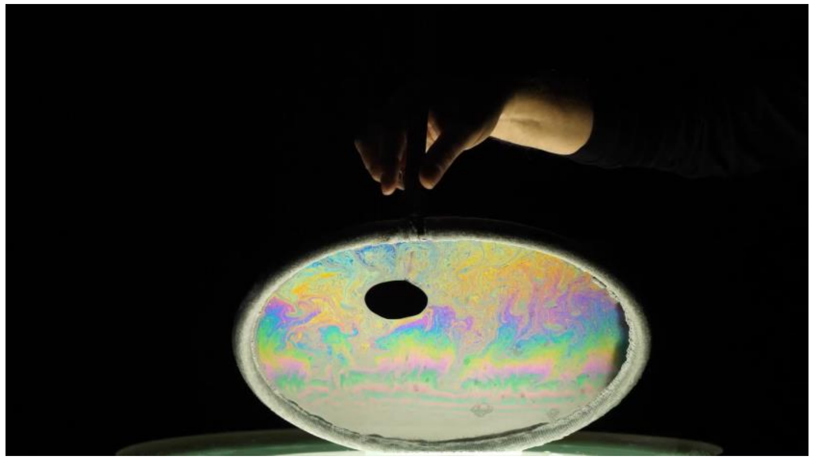
Institut Charles SADRON
CNRS - UNISTRA - STRASBOURG

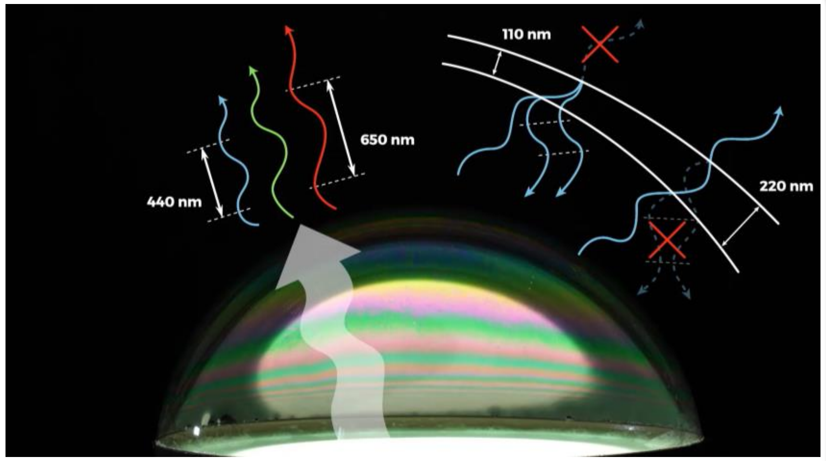
Ce que l’on a appris la semaine derniere



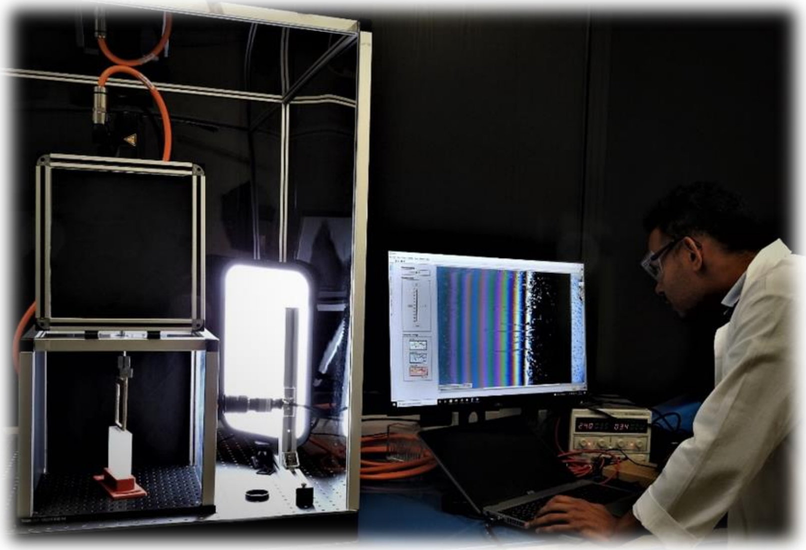
Molécules tensio-actives:

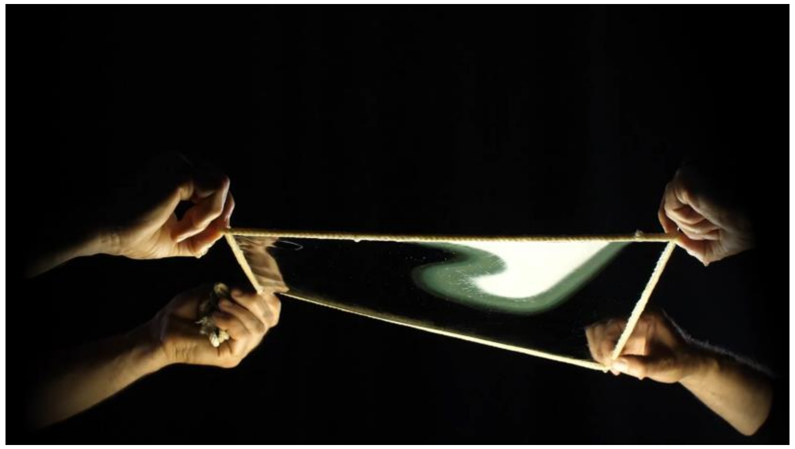
- Réduisent la tension de surface γ;
- Stabilisent les films d’eau -> Films de savons.



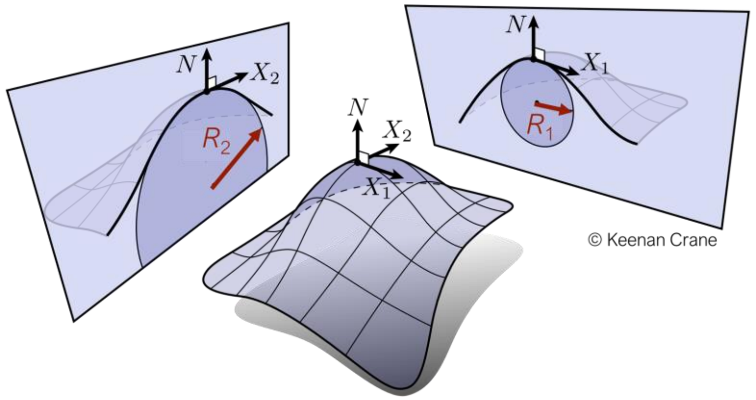


Les interférences en lumière blanche nous renseignent sur l’épaisseur du film.



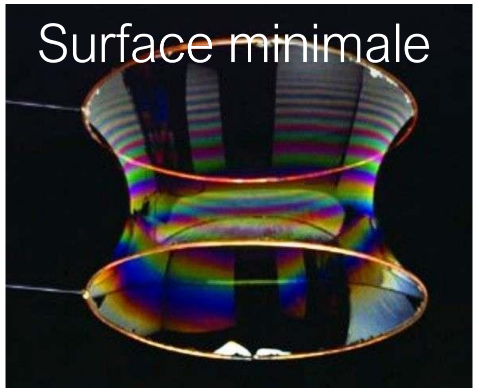


Les surfaces peuvent être planes ou courbées.



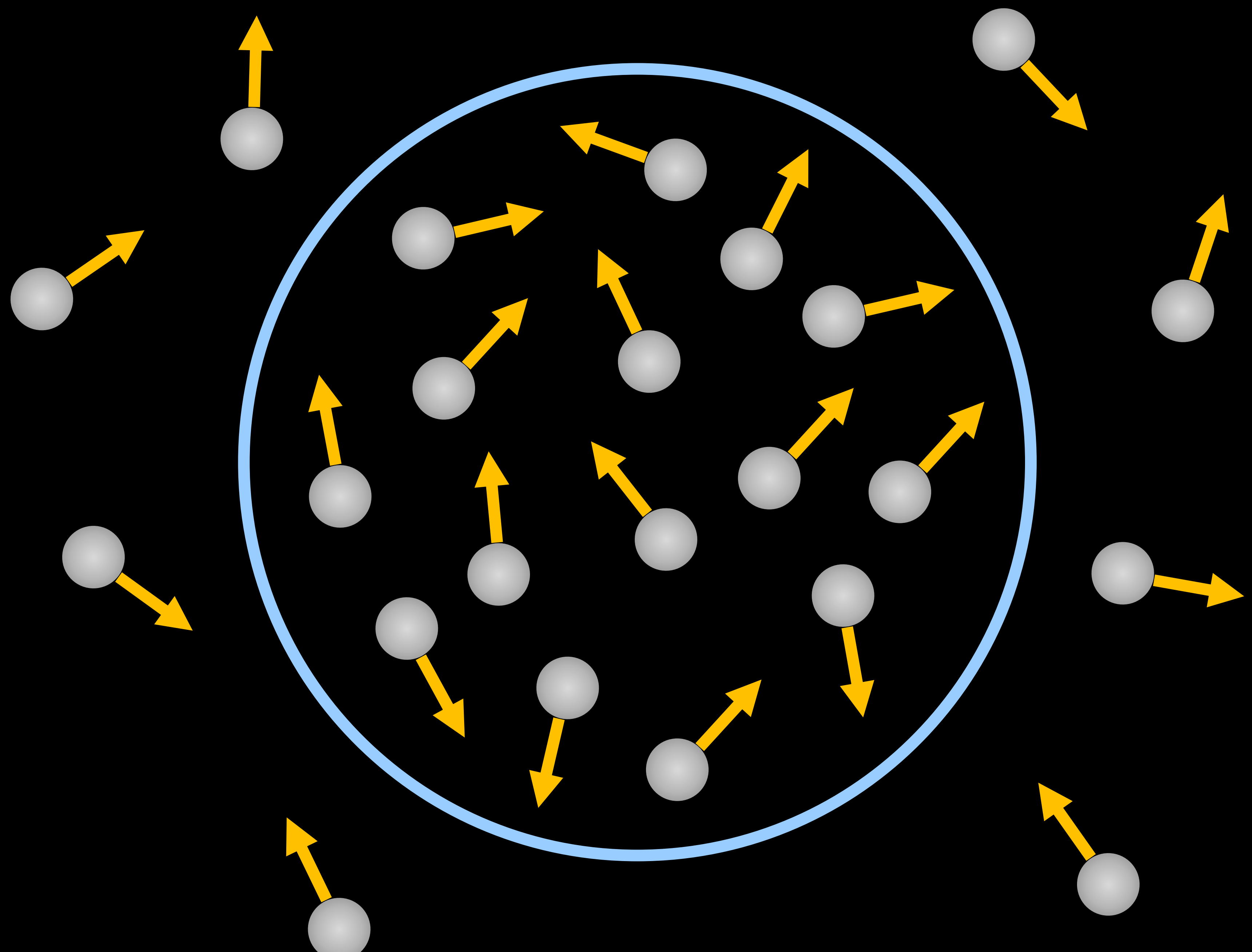
Courbure moyenne:

$$H = \frac{1}{2}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

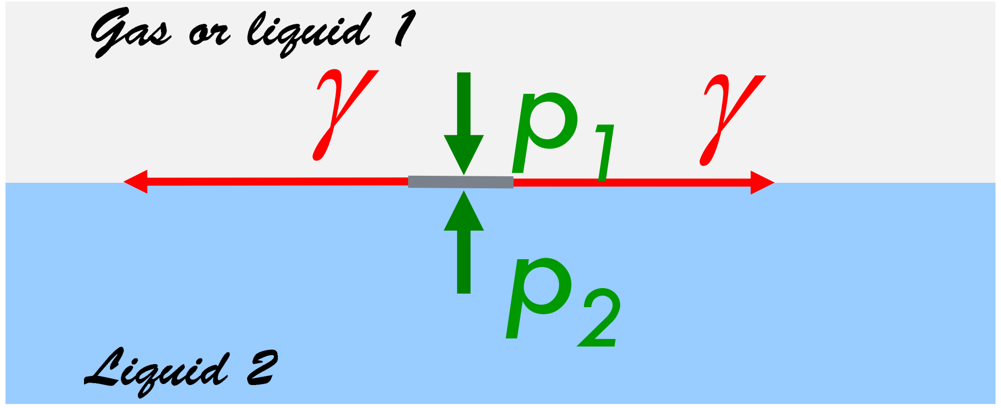


$$H = 0$$

Partie 1 : pression dans des bulles/mousses et conséquences



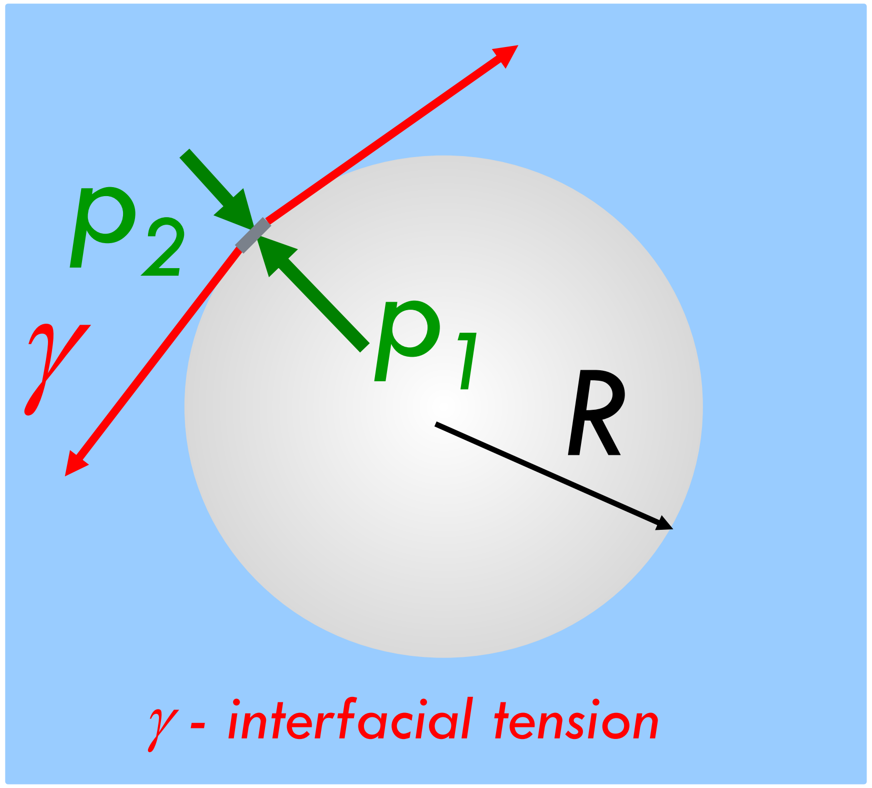
Interfaces courbées



A l'équilibre $\sum \vec{f} = \vec{0}$

horizontalement $\gamma\ell - \gamma\ell = 0$

verticalement $\Delta p = p_1 - p_2 = 0$



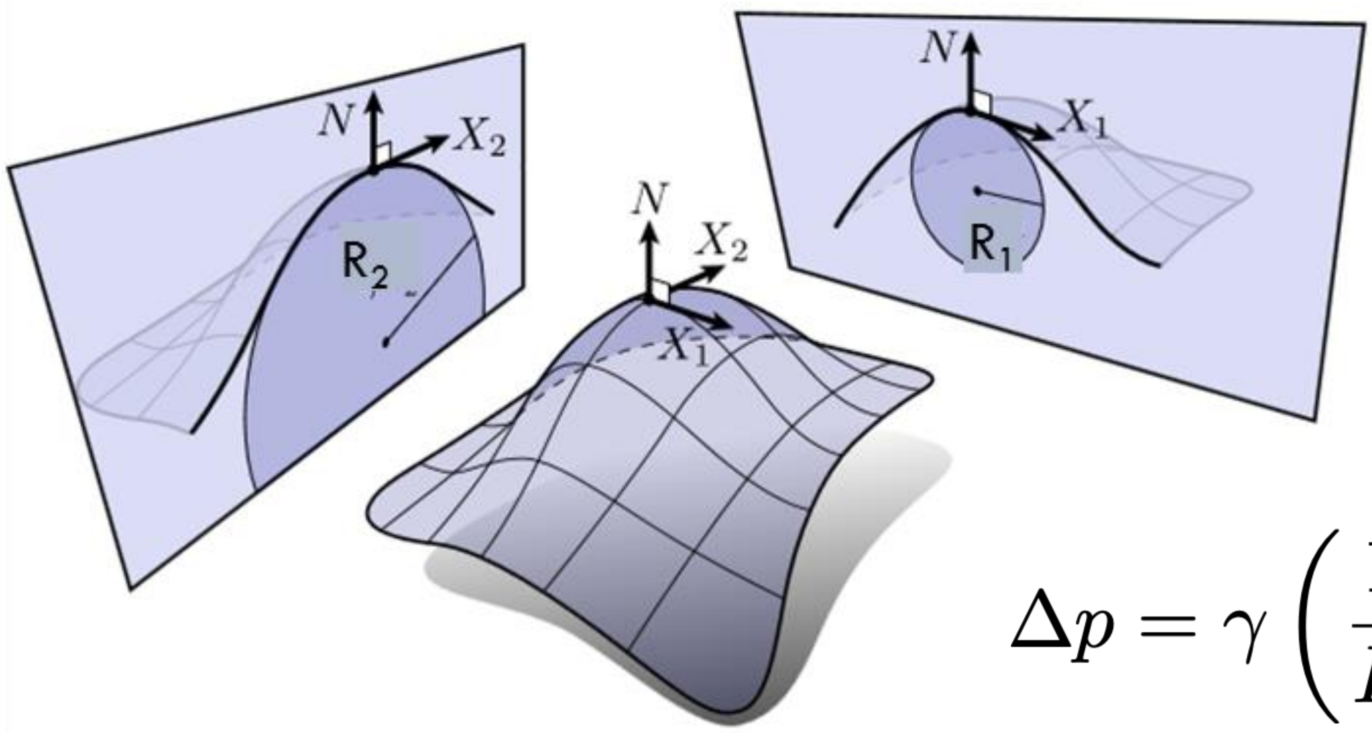
A l'équilibre, si la surface est courbée $\Delta p \neq 0$

Pour une sphère on montre

$$\Delta p = p_1 - p_2 = \frac{2\gamma}{R}$$

Interfaces courbées: loi de Young-Laplace

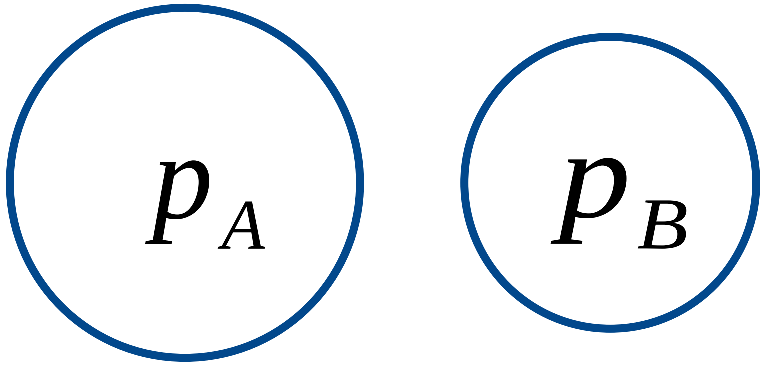
A l'équilibre, pour une surface courbée quelconque



$$\Delta p = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = 2\gamma H$$

La différence de pression contrôle la courbure:

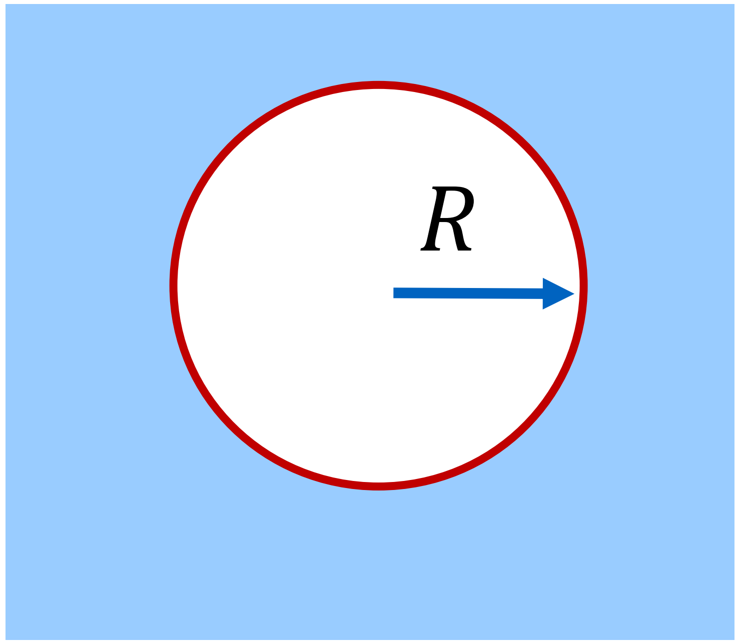
- $\Delta p = 0 \implies \mathrm{H} = 0$, surface minimale;
- $\Delta p \neq 0 \implies \mathrm{H} \neq 0$.



$$p_A < p_B$$

Conséquences importantes:
pression dans petites bulles > pression grandes bulles

Pression dans les bulles (et les gouttes)

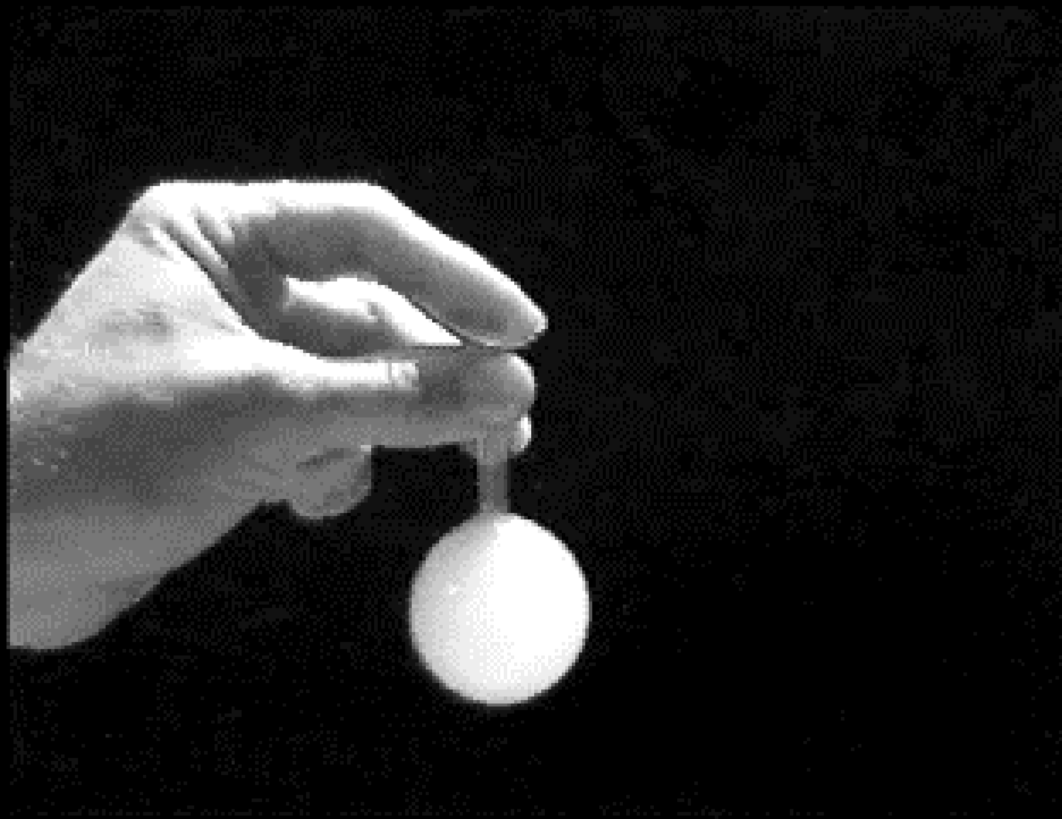


$$\Delta p = \frac{2\gamma}{R}$$

Pression élevée pour des petites bulles ➡ **Effets de pression peuvent être très importants**

γ (mN/m)	*R* (µm)	Pression (Pa)
1	1	20000
	10	2000
	100	200
	1000	20
	10000	2
10	1	200000
	10	20000
	100	2000
	1000	200
	10000	20

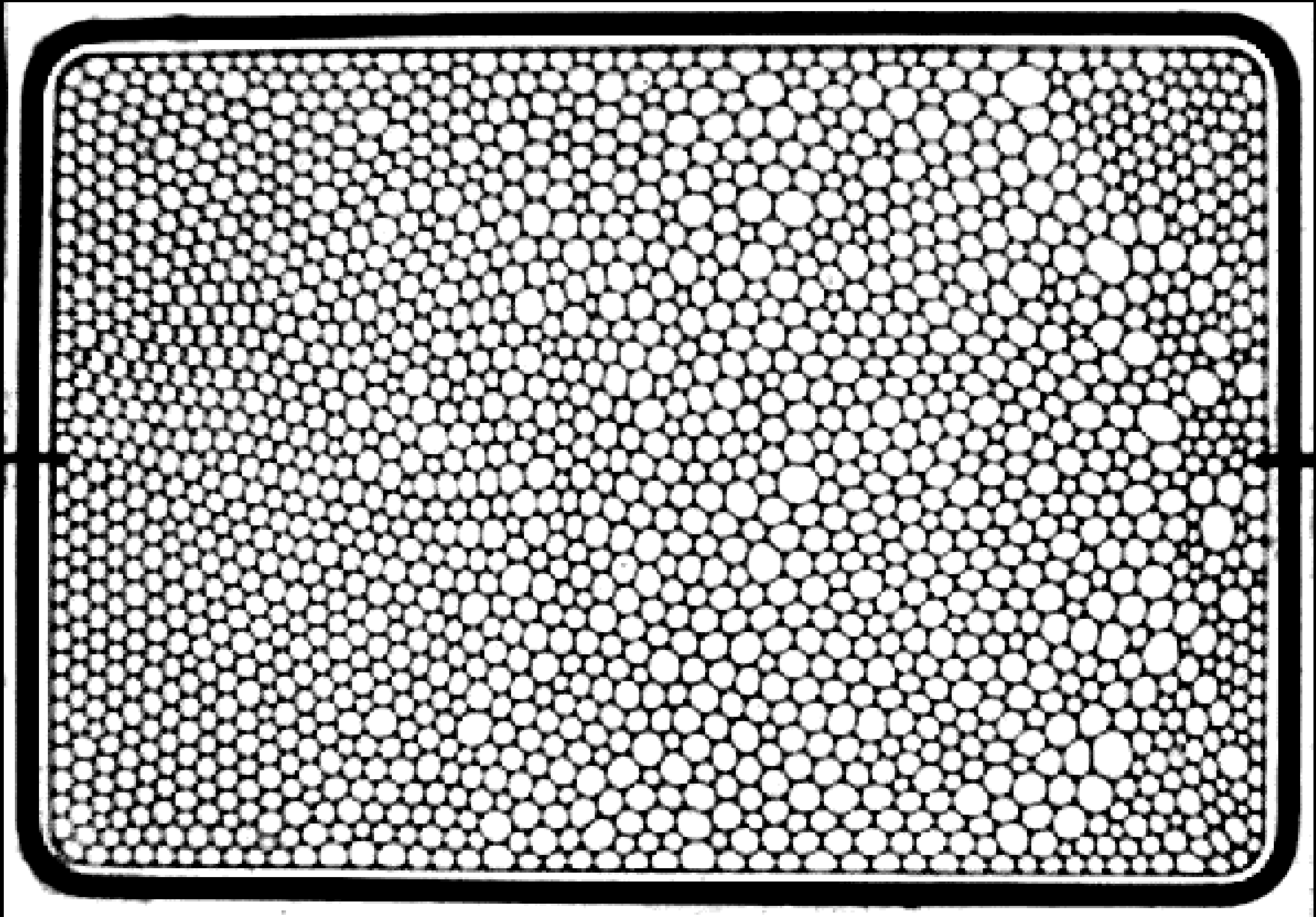
Pression atmosphérique
101325 Pa



(D. Quere)

Pression de la bulle ~ (rayon de la bulle)$^{-1}$

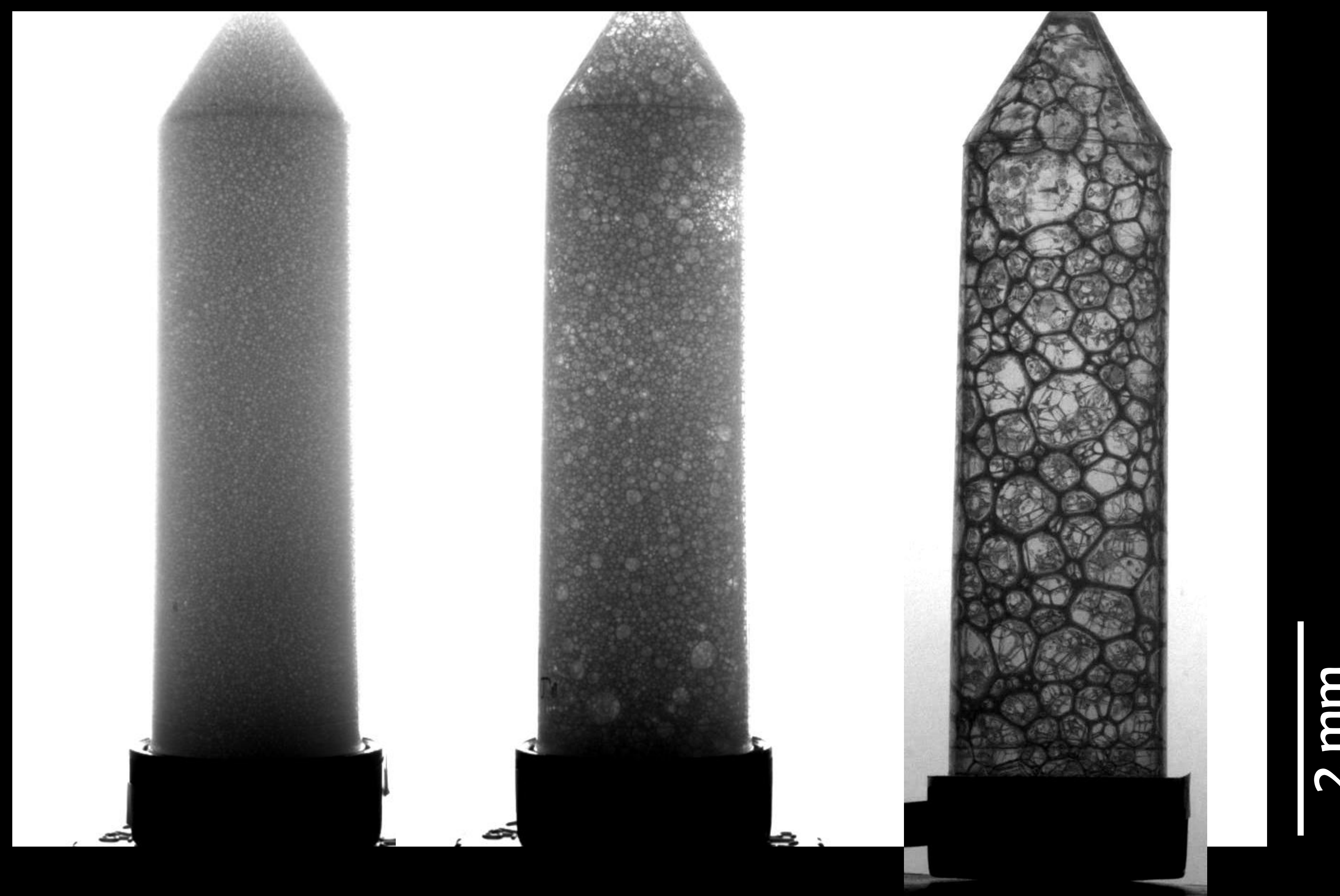
Mûrissement



0 min

Les grandes mangent les petites !!!

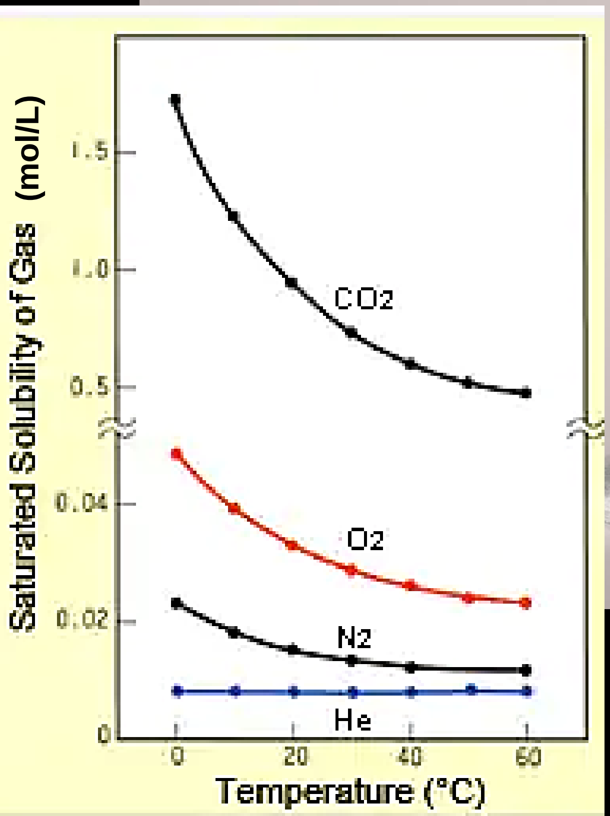
Mousse à raser



1 semaine — 1 mois — 1.5 anneés

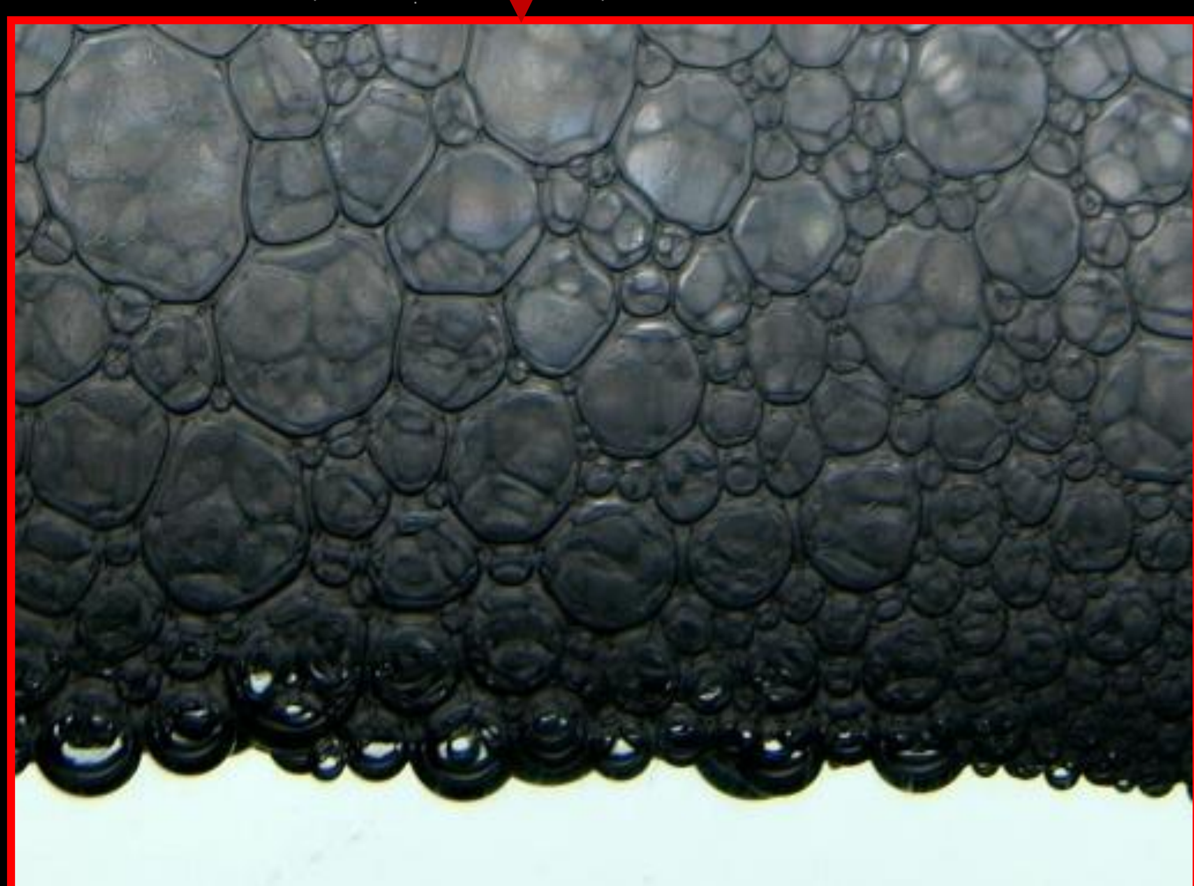
temps

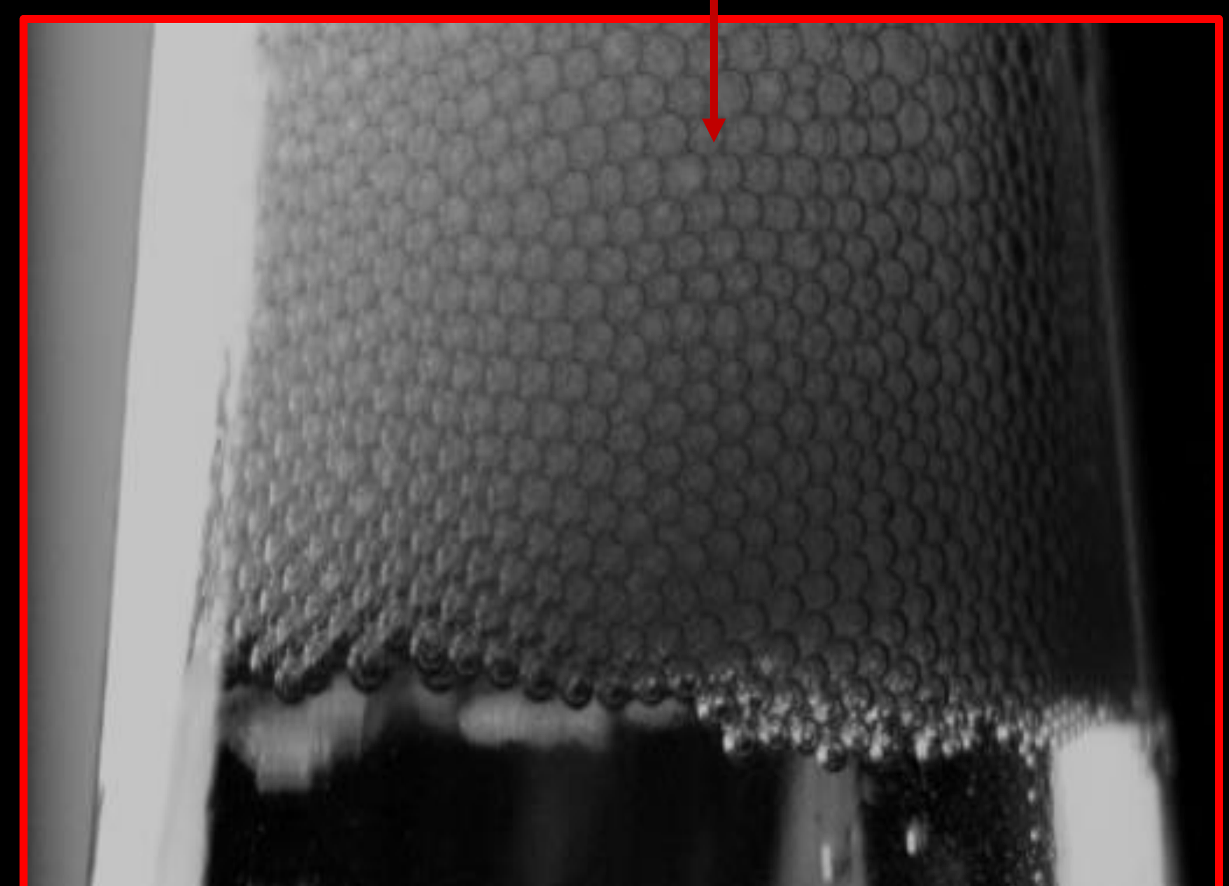
UNE AUTRE RAISON DE BOIRE VITE CA BIERE !



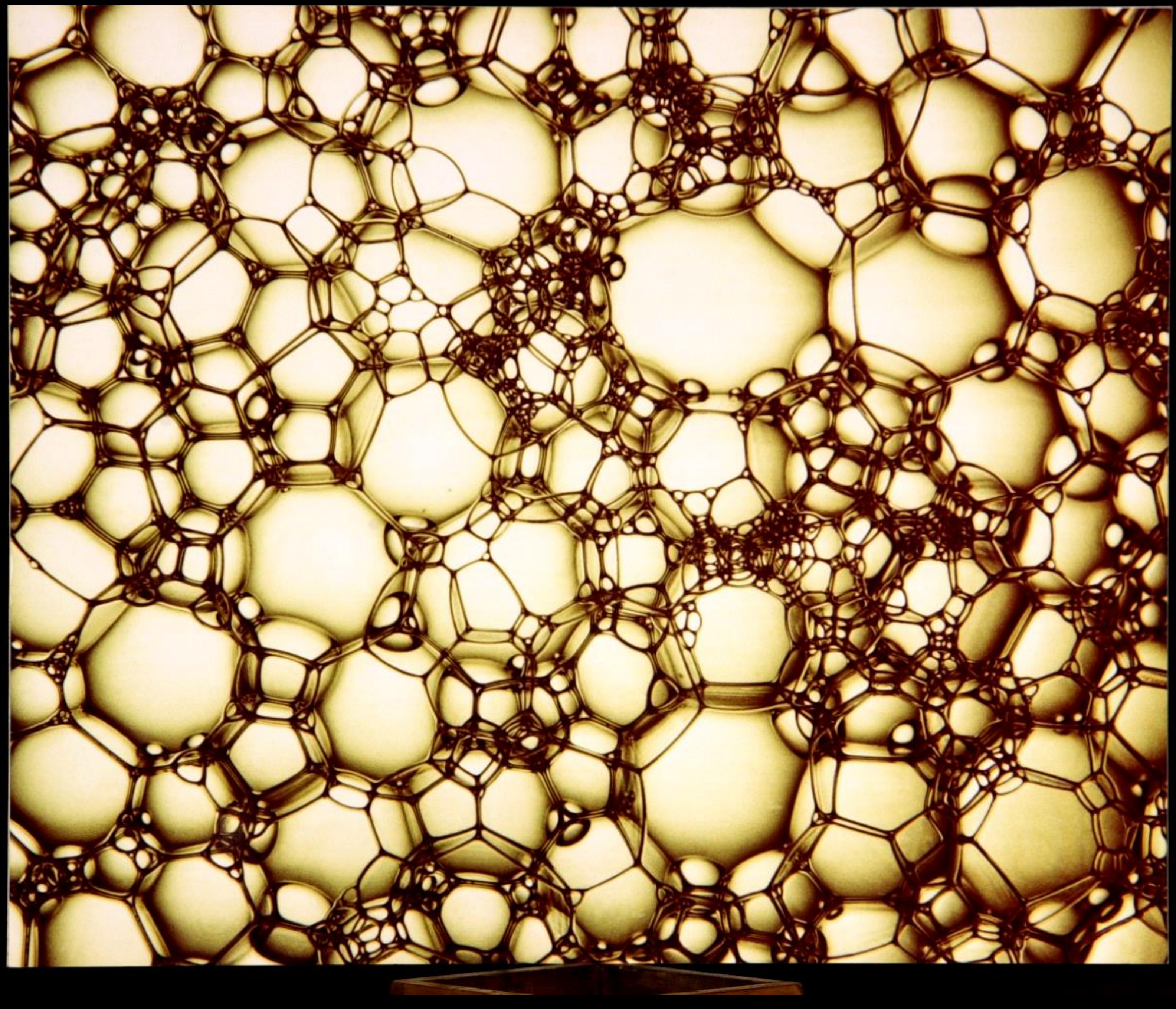
Les Irlandais ont trouvé une solution...

QUELLE EST LA DIFFERENCE ENTRE CES DEUX MOUSSES ?

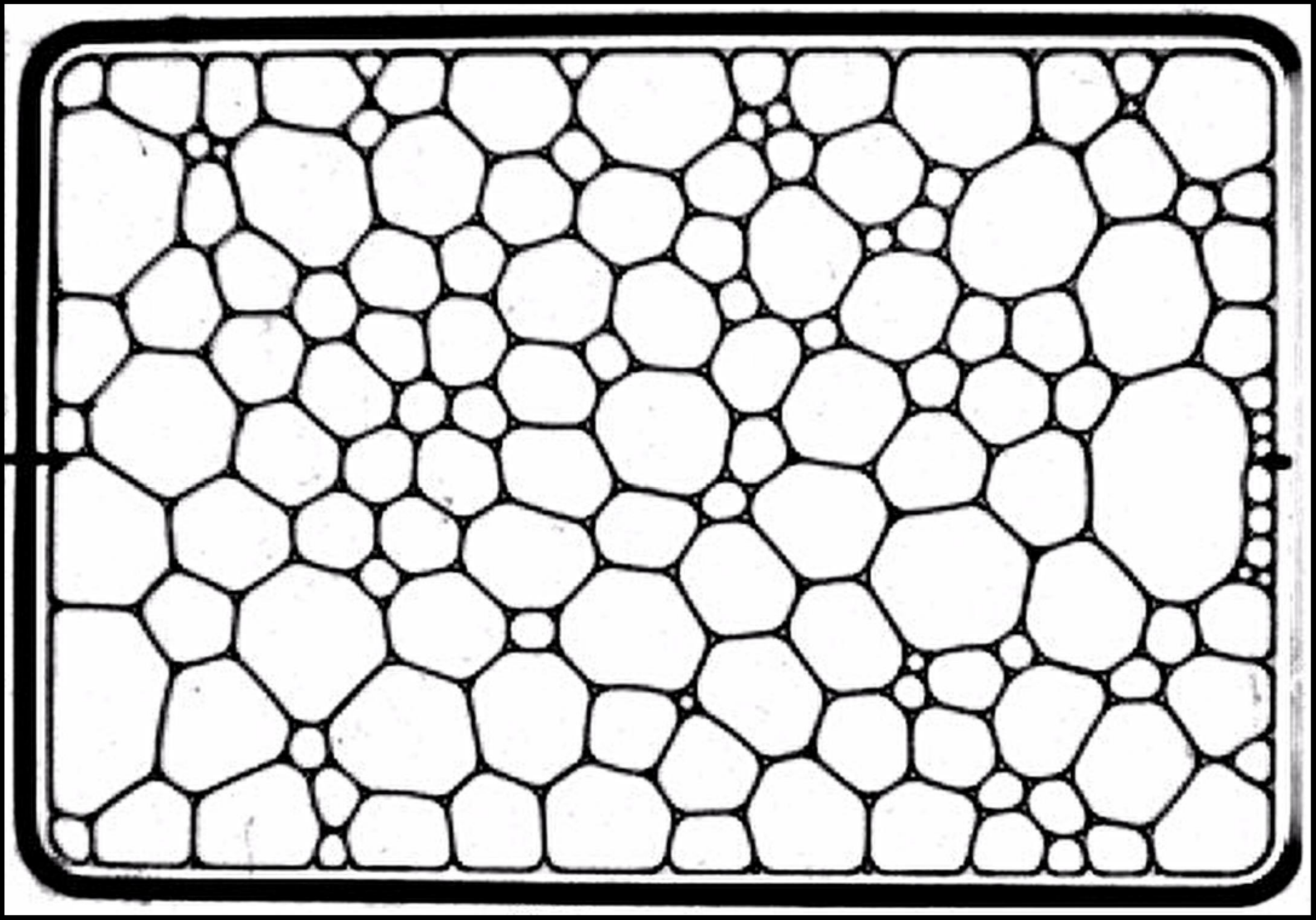




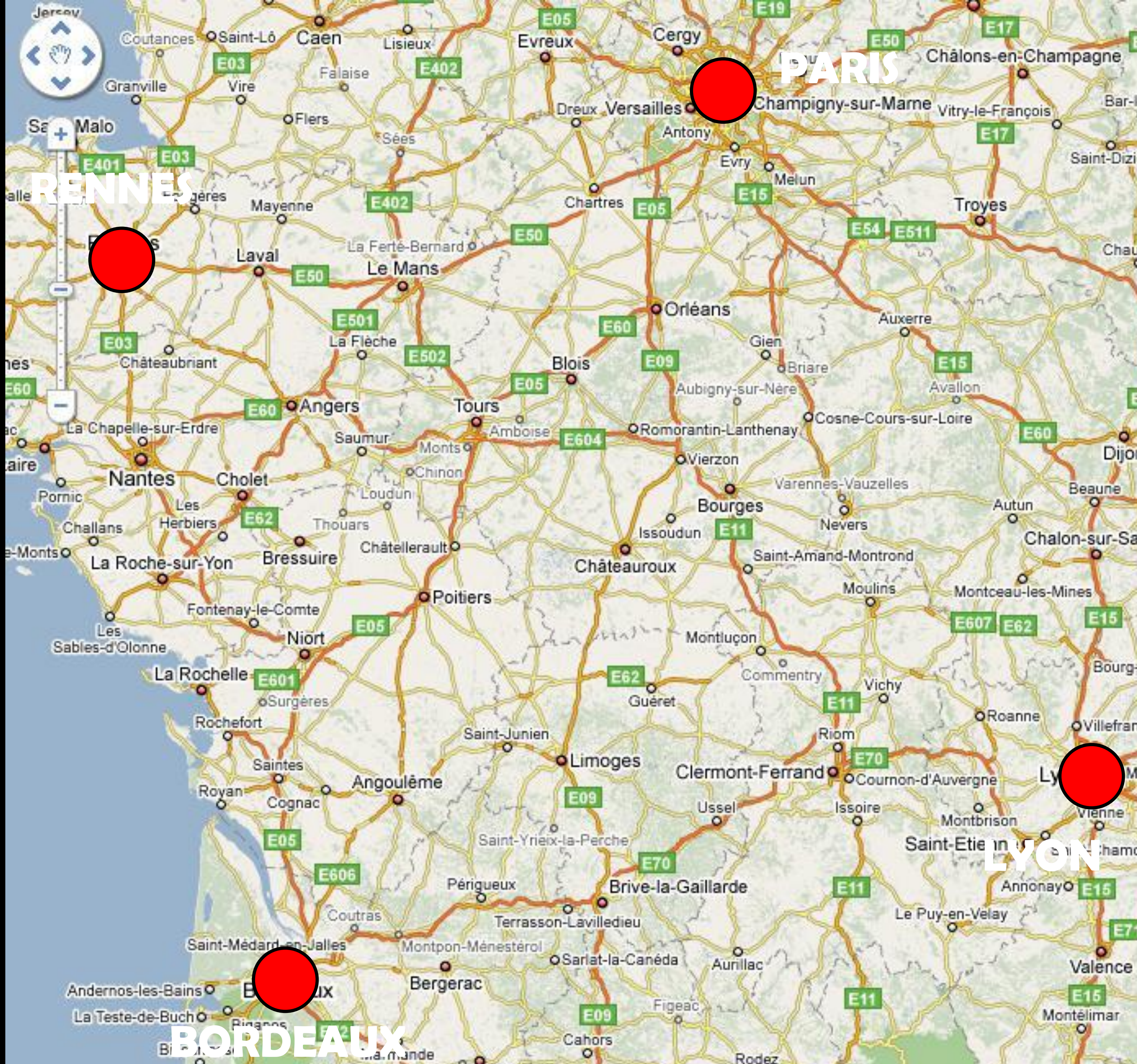
Partie 2:
La structure des mousses



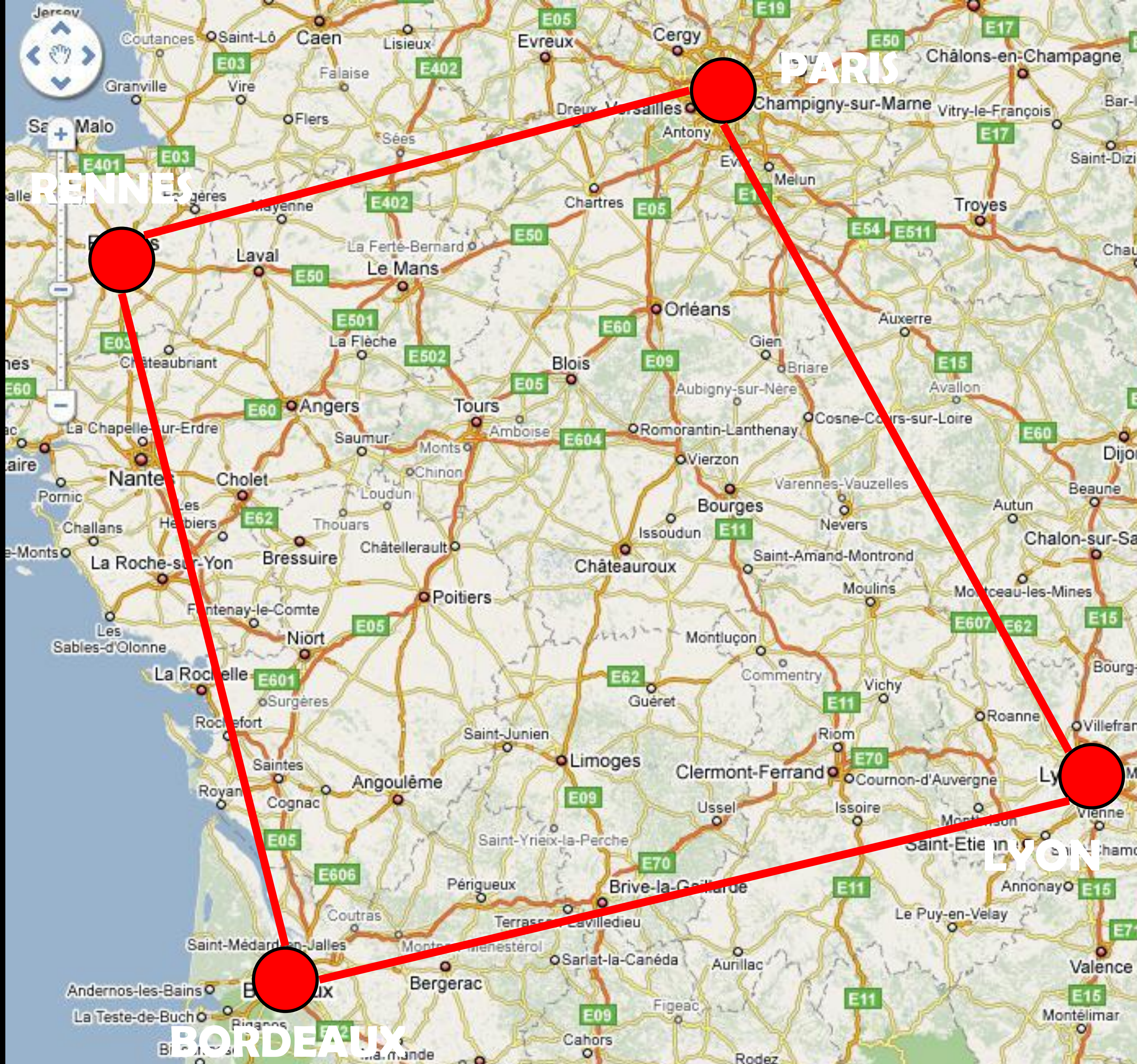
UNE MOUSSE ECRASEE



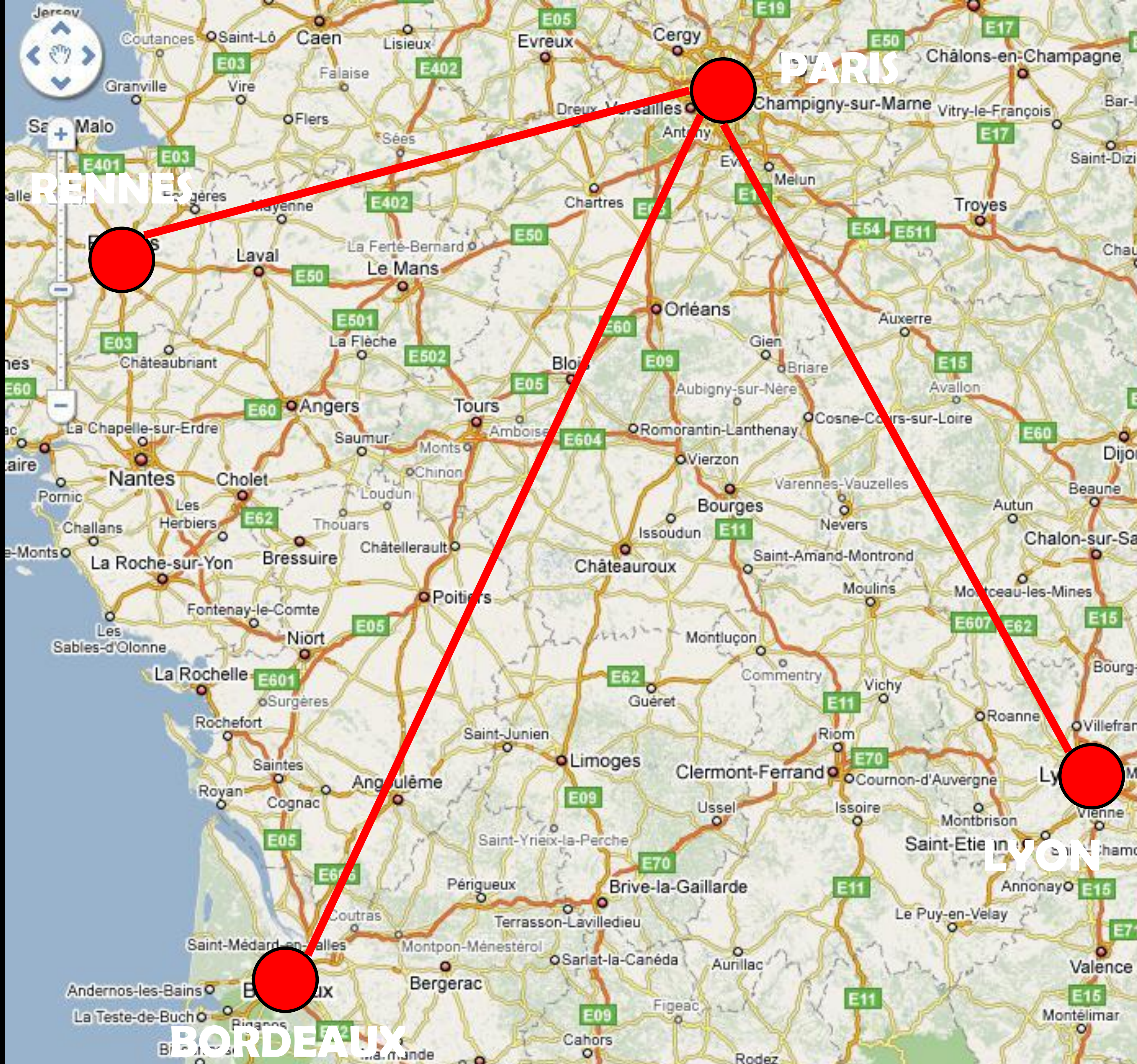
Mousse 3D: minimization de l’aire des interfaces
Mousse 2D: minimization de la longeur des lignes



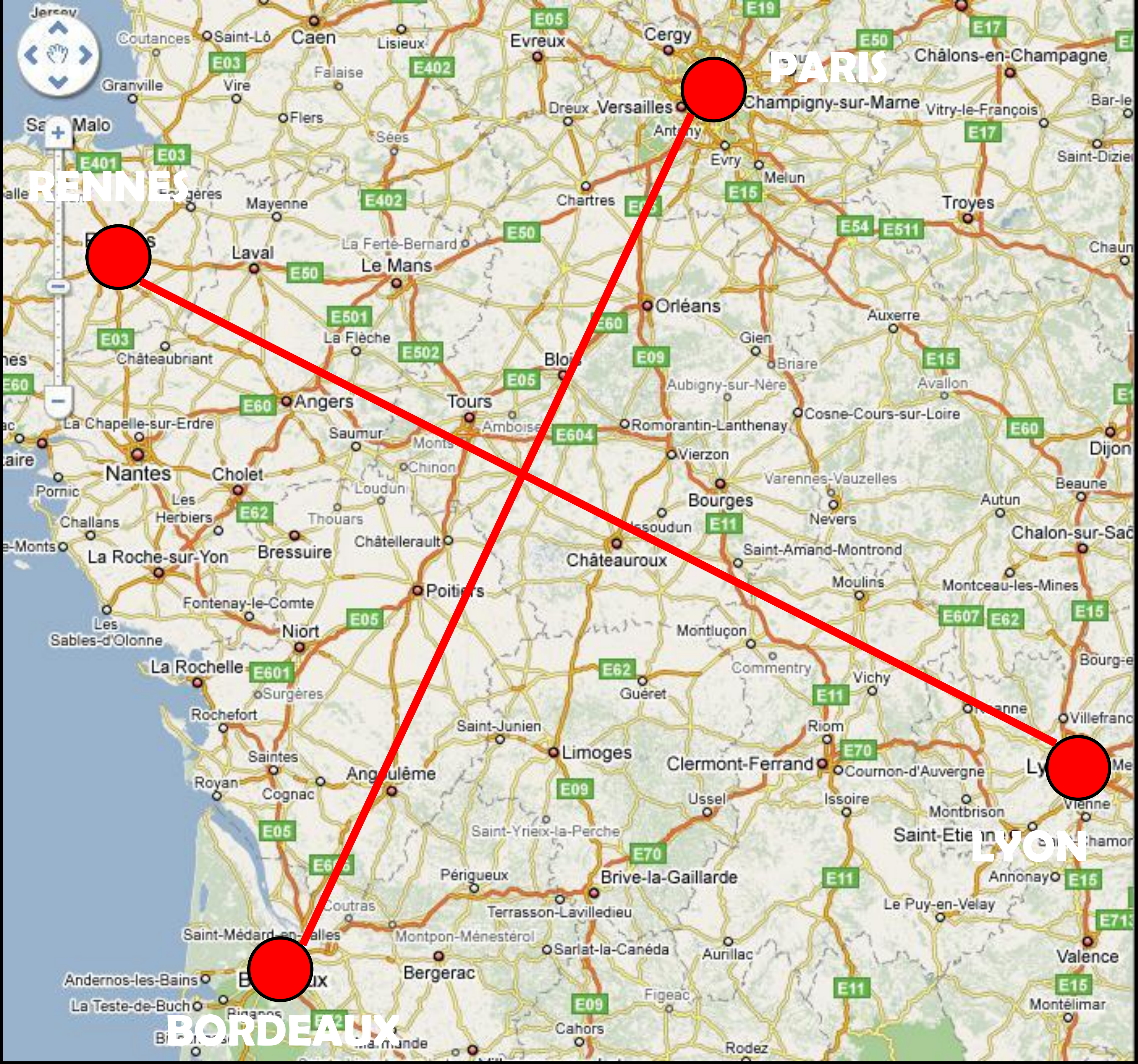
Comment connecter Paris, Rennes, Bordeaux et Lyon en minimisant la longueur total des chemins de ferre ?



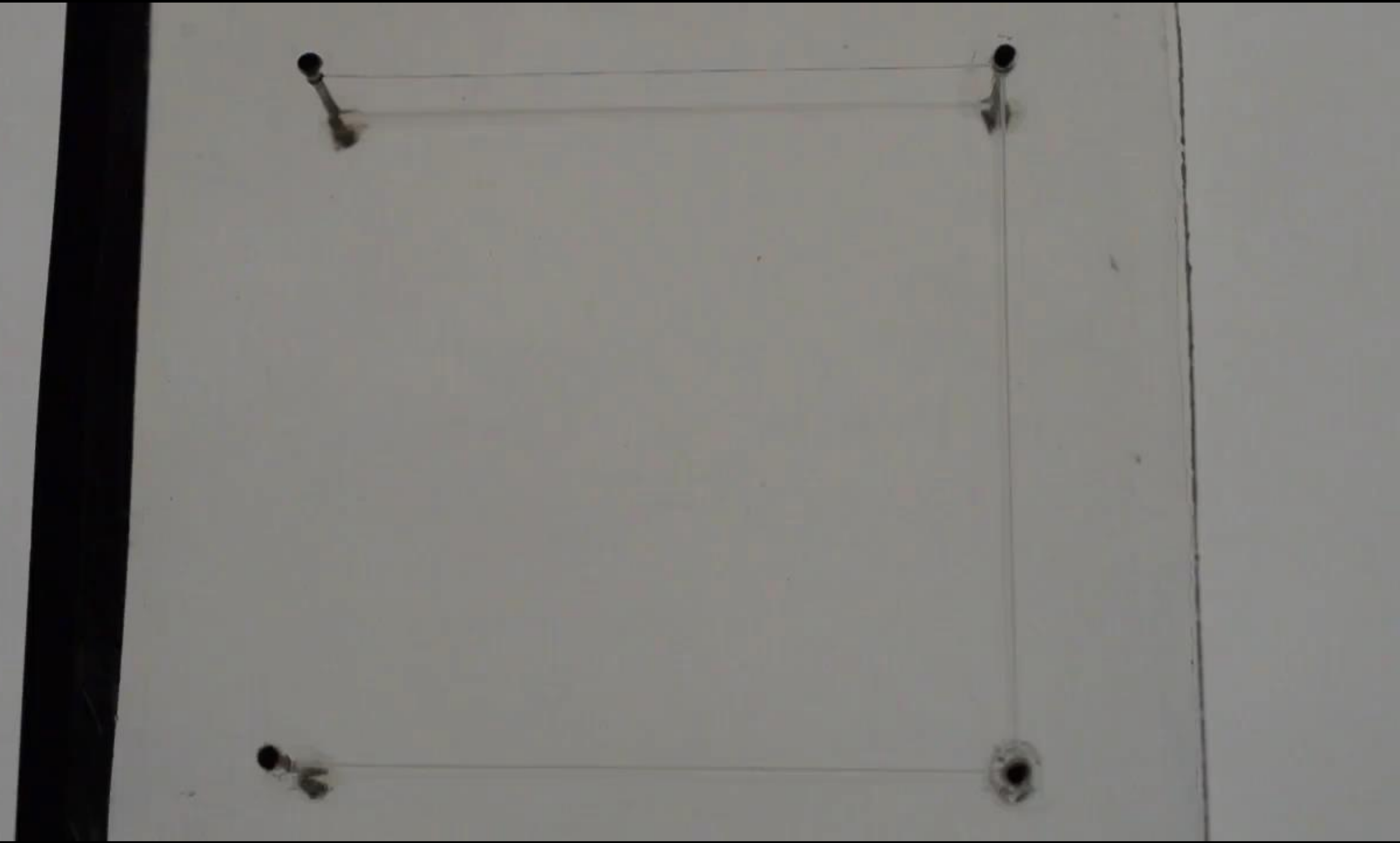
Suggestion ?

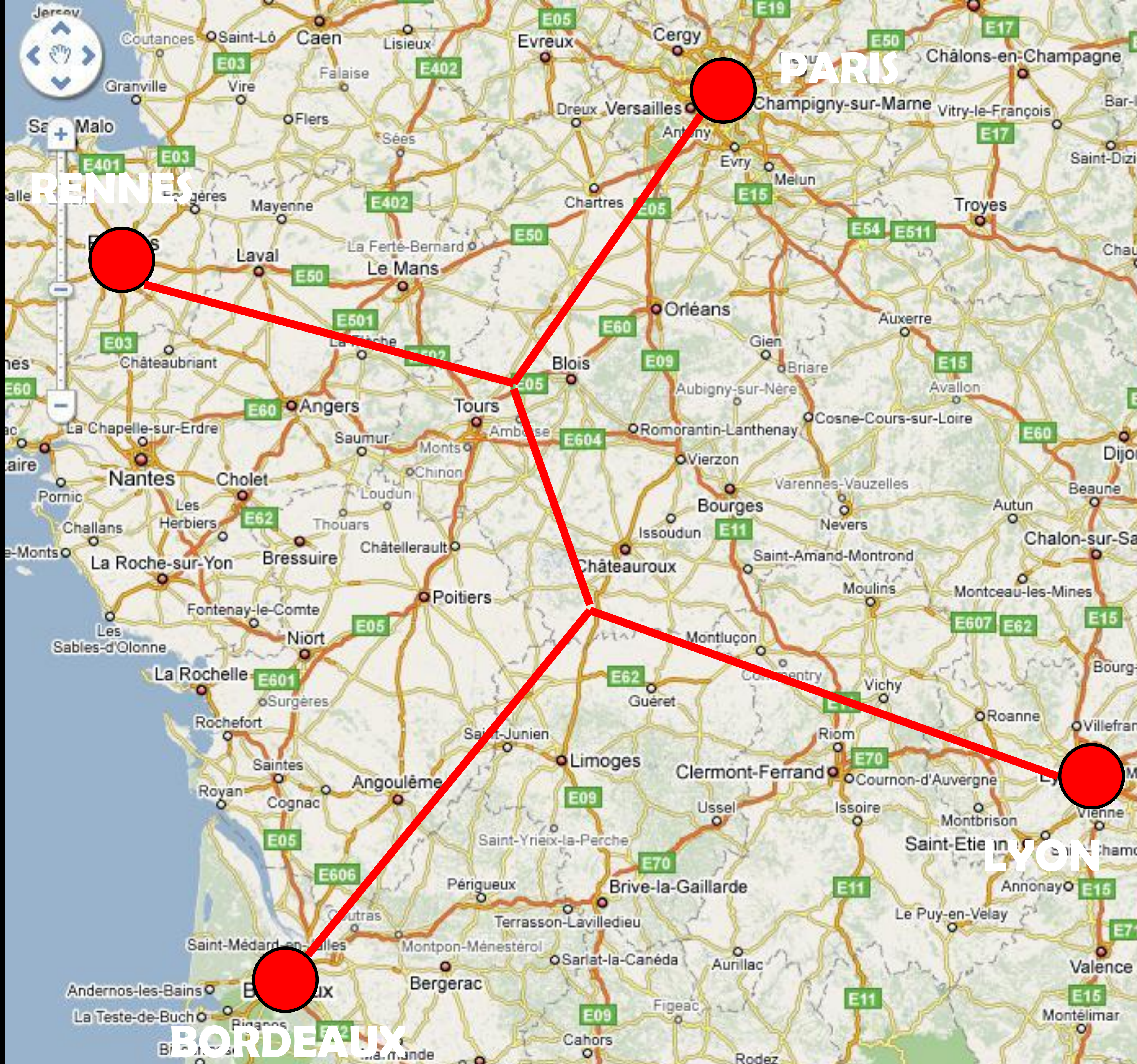


Les français savent faire mieux !

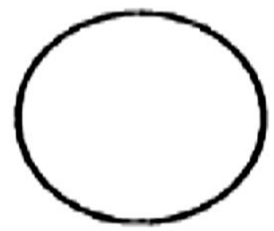
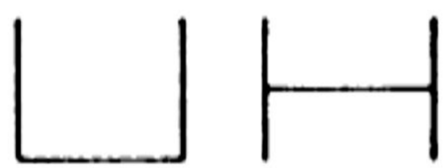
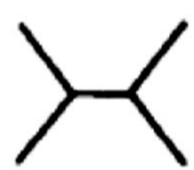


Encore mieux !

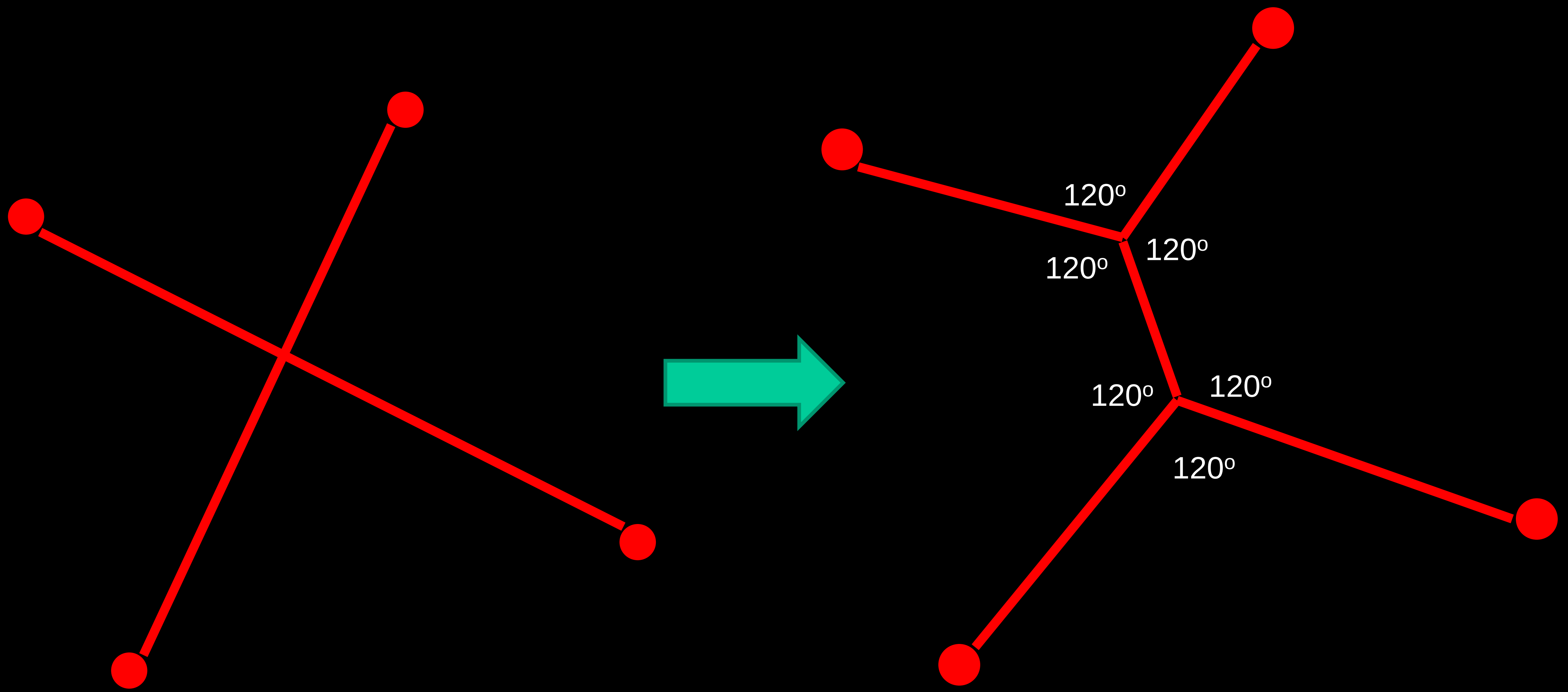




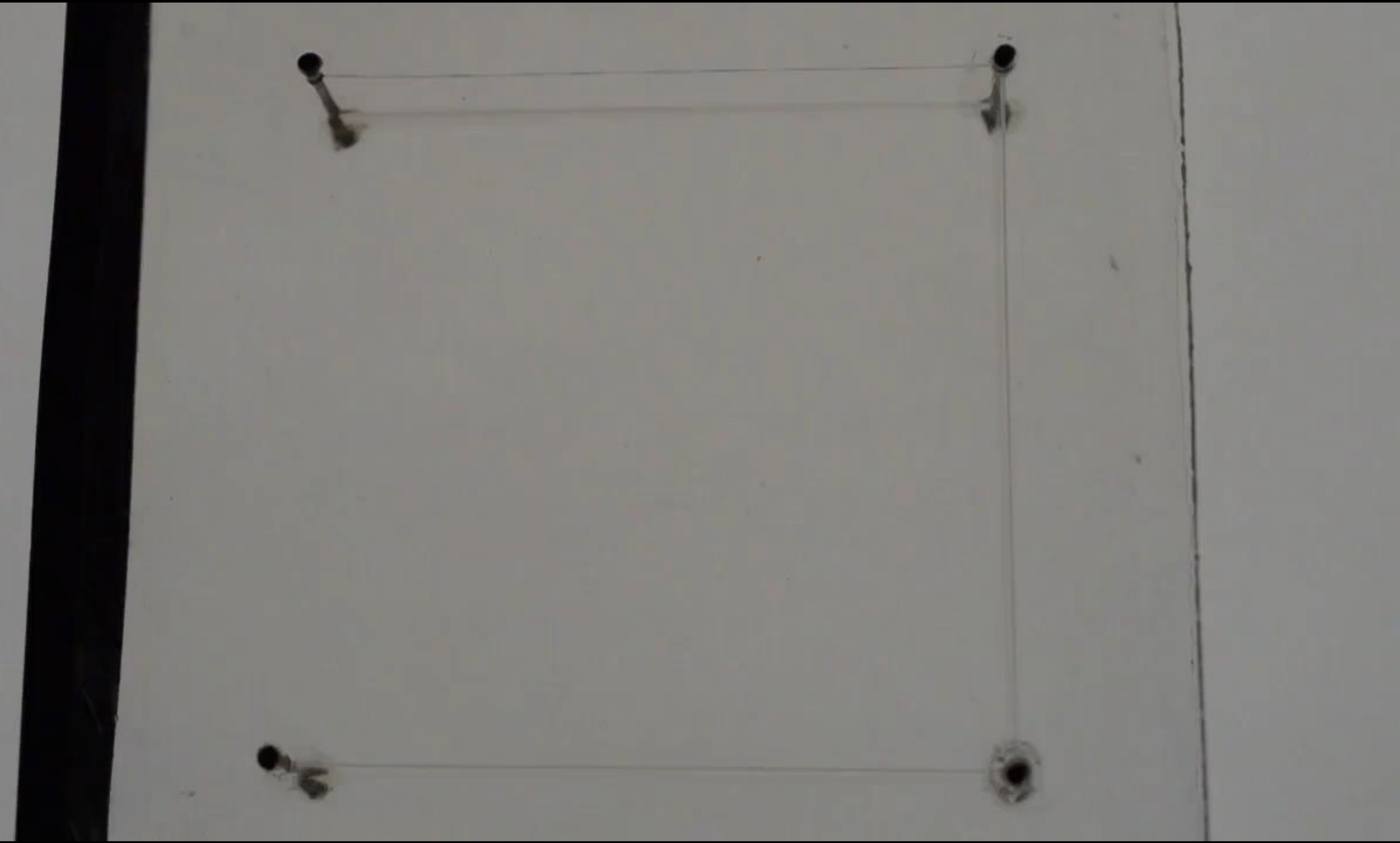
Mais la nature est la meilleur !

Motorway Configuration	LENGTH	
	$4+2\sqrt{2}$	6·82
	$\pi\sqrt{2}$	4·44
	4	4·00
	3	3·00
	$2\sqrt{2}$	2·83
	$1+\sqrt{3}$	2·73

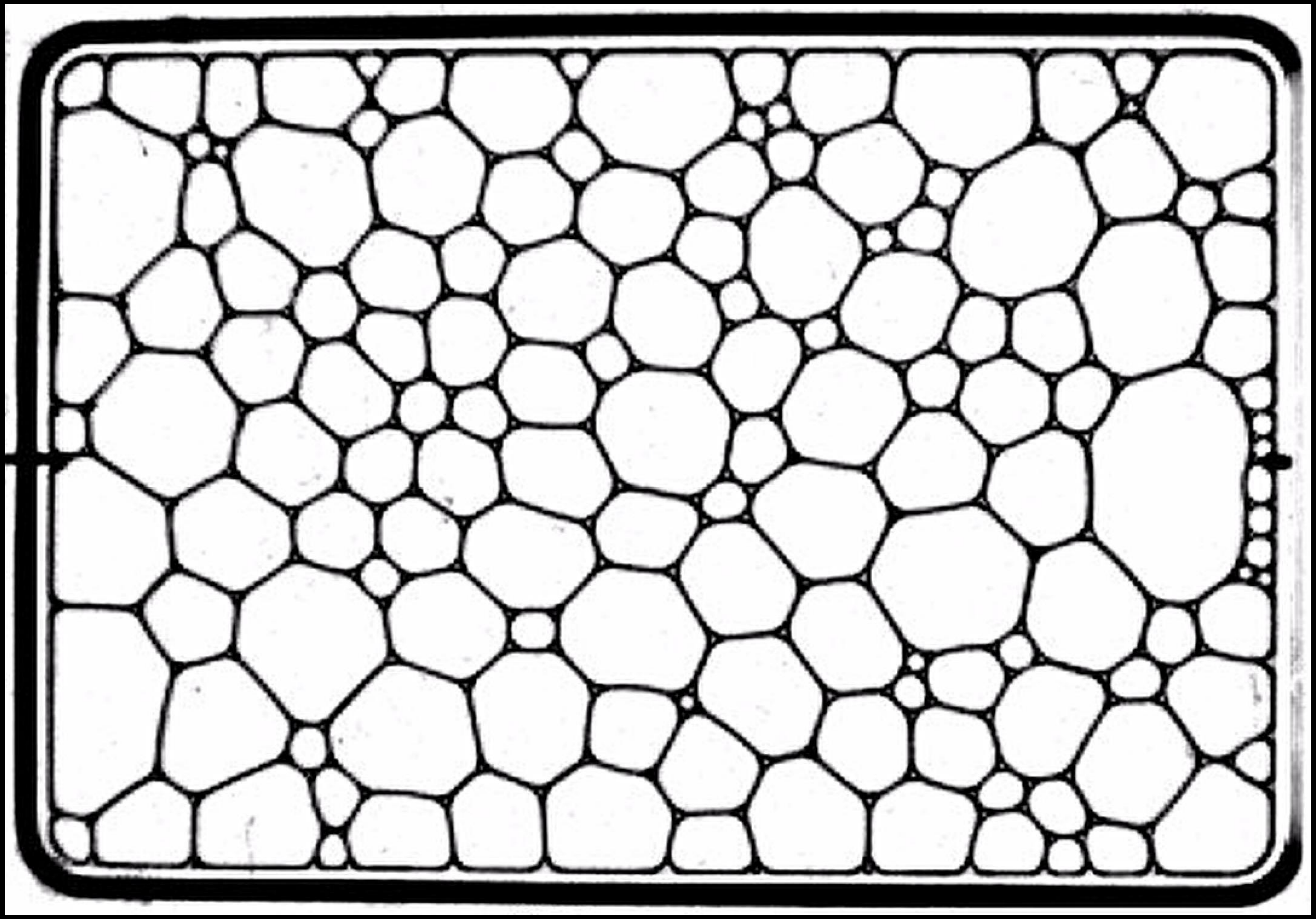
Le problème de Steiner



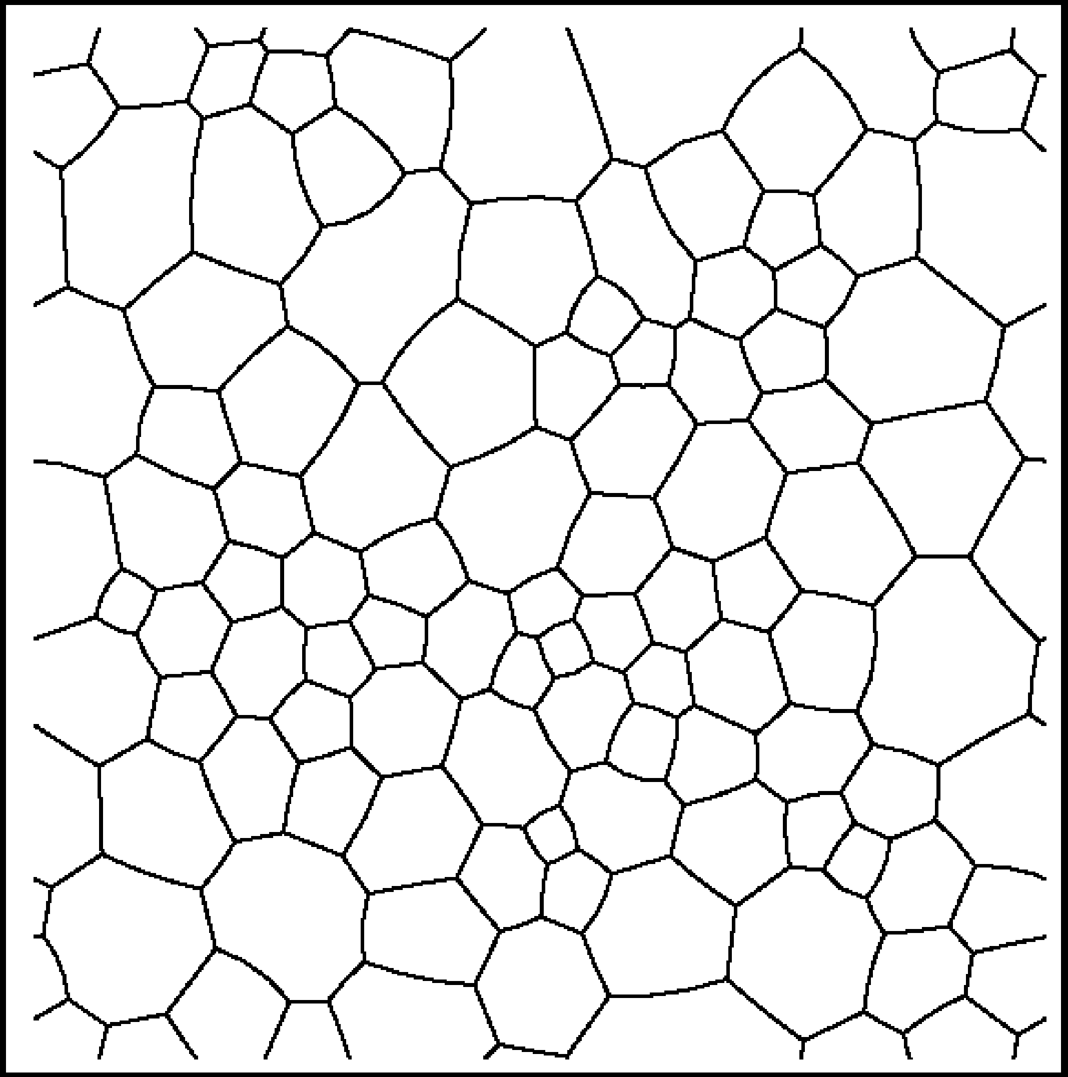
Trois films se rencontrent toujours à 120˚.



Experience



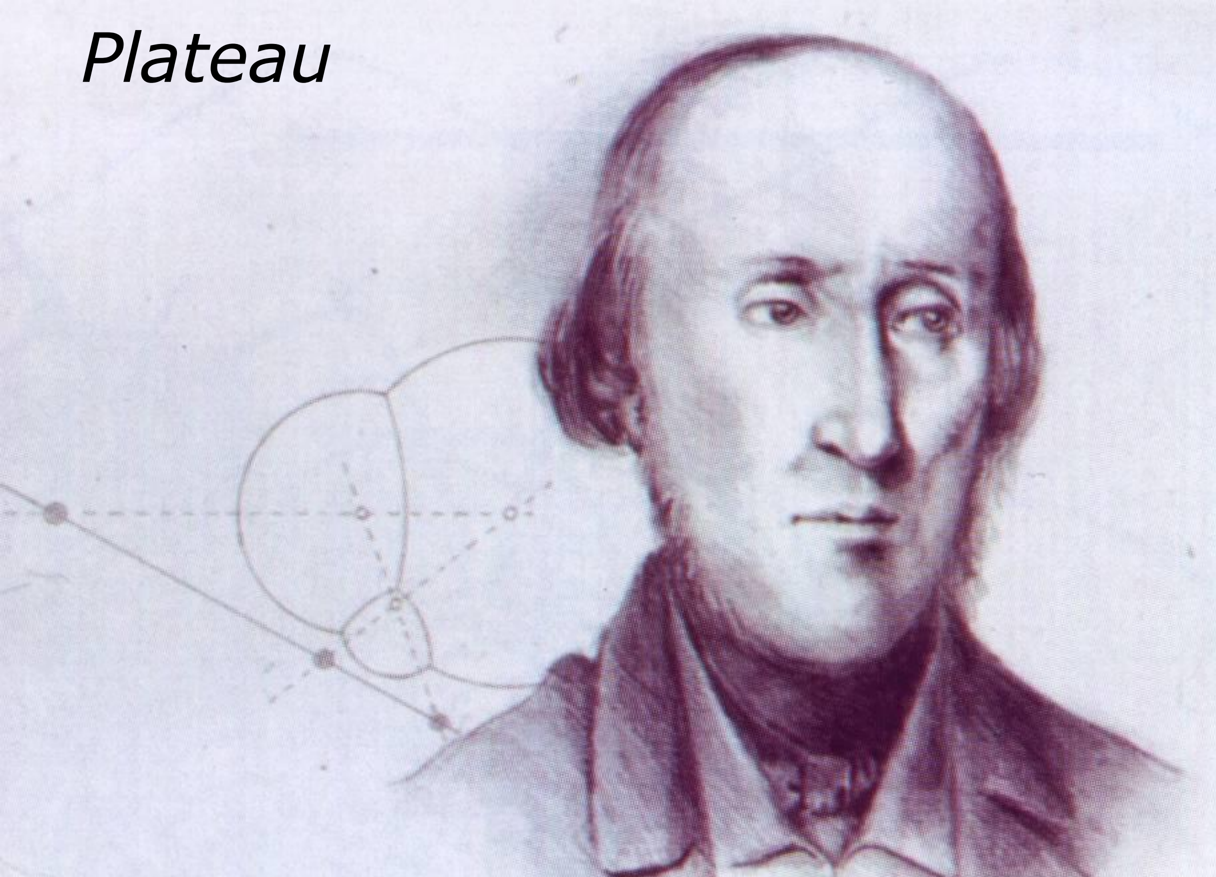
Simulation

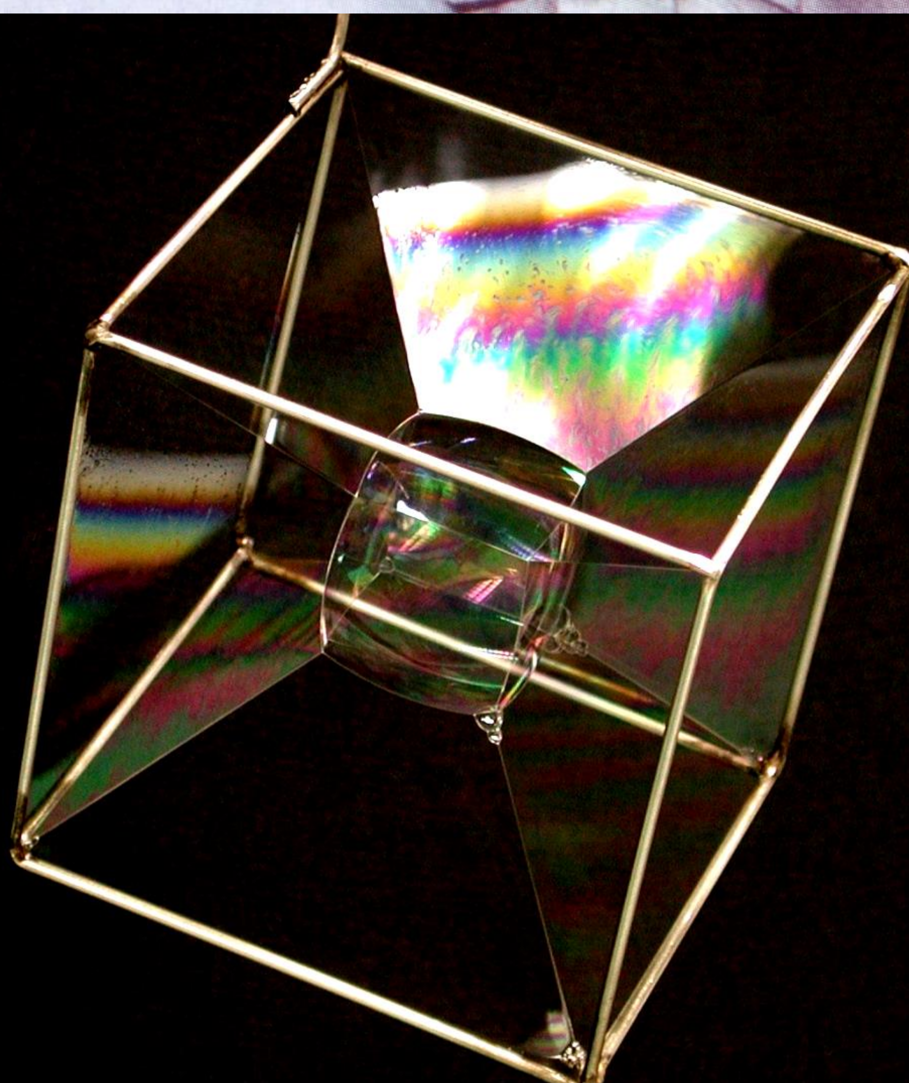


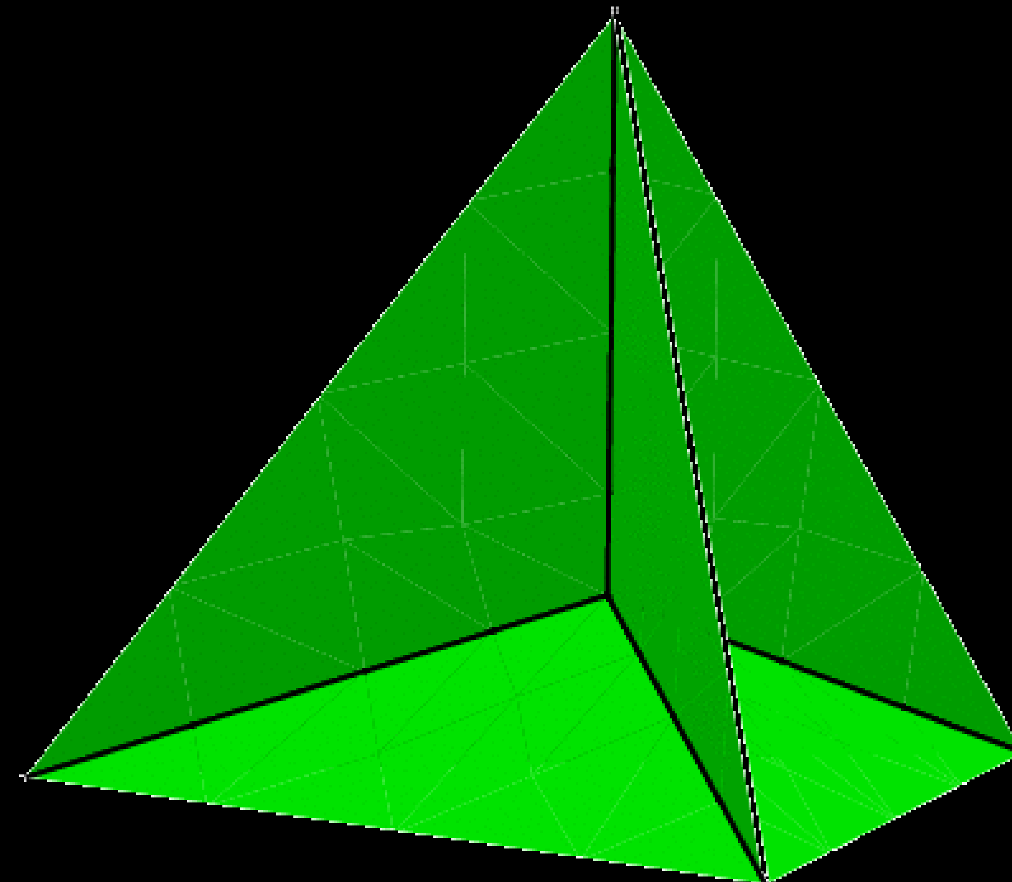
© Gerard Kingma

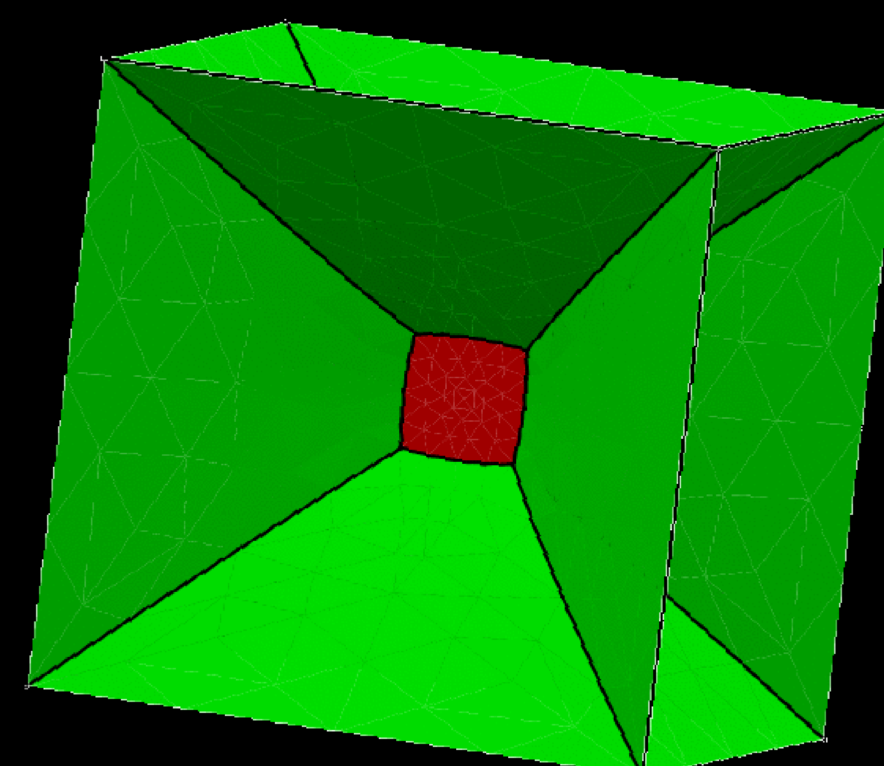
Exemple classique de manque de communication entre la recherche et les domaines appliquées …

ET EN 3D ?

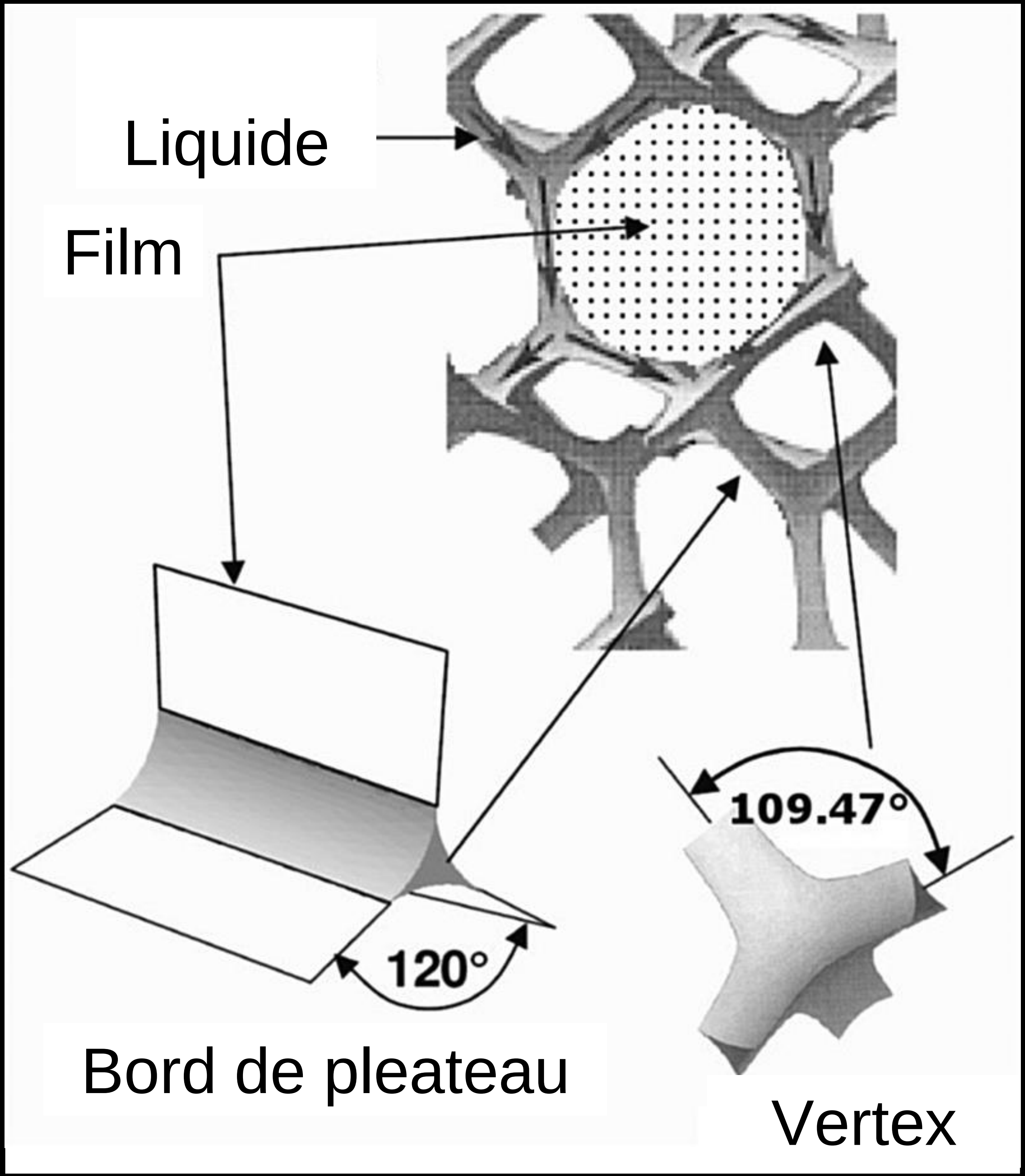

Plateau



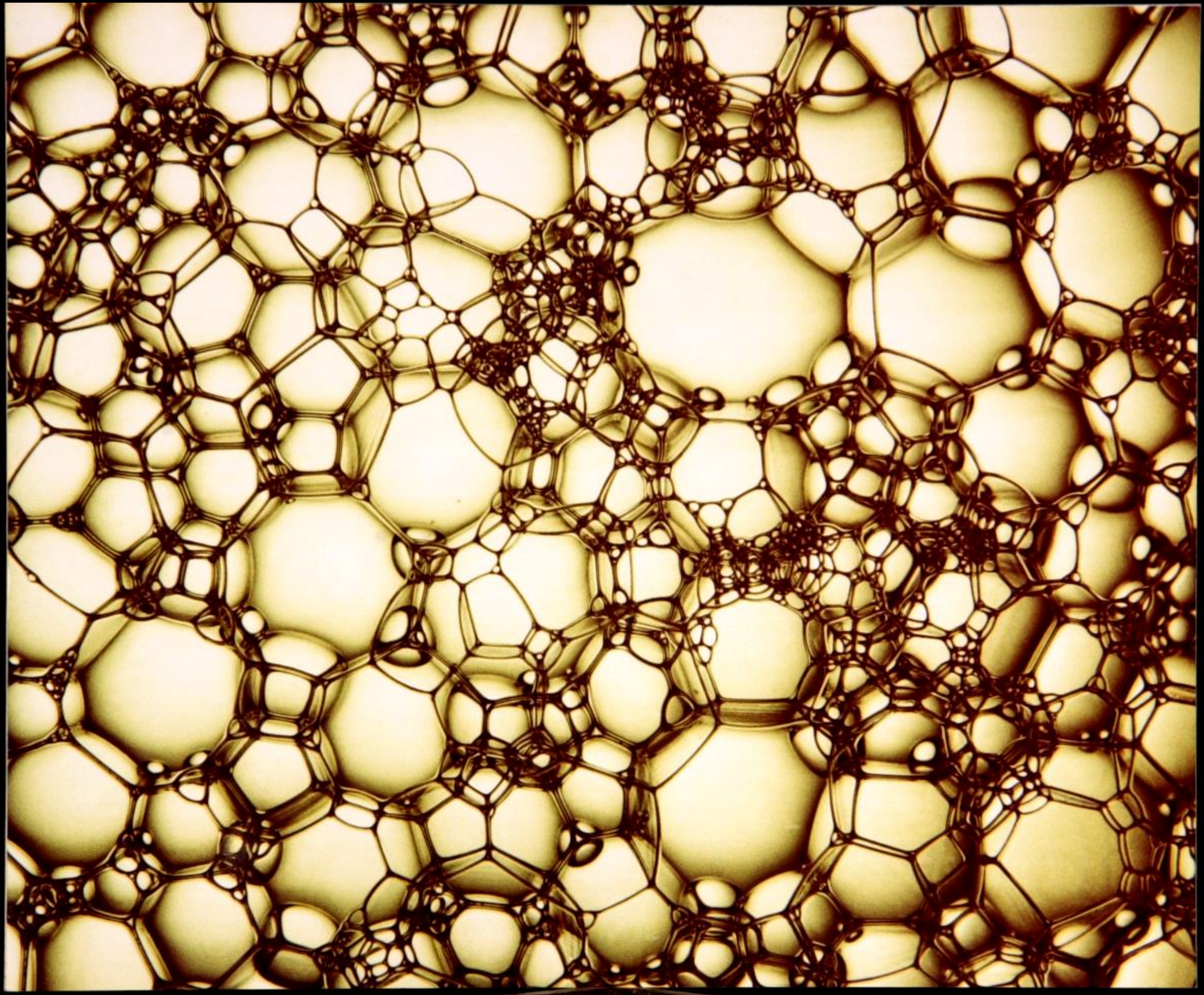




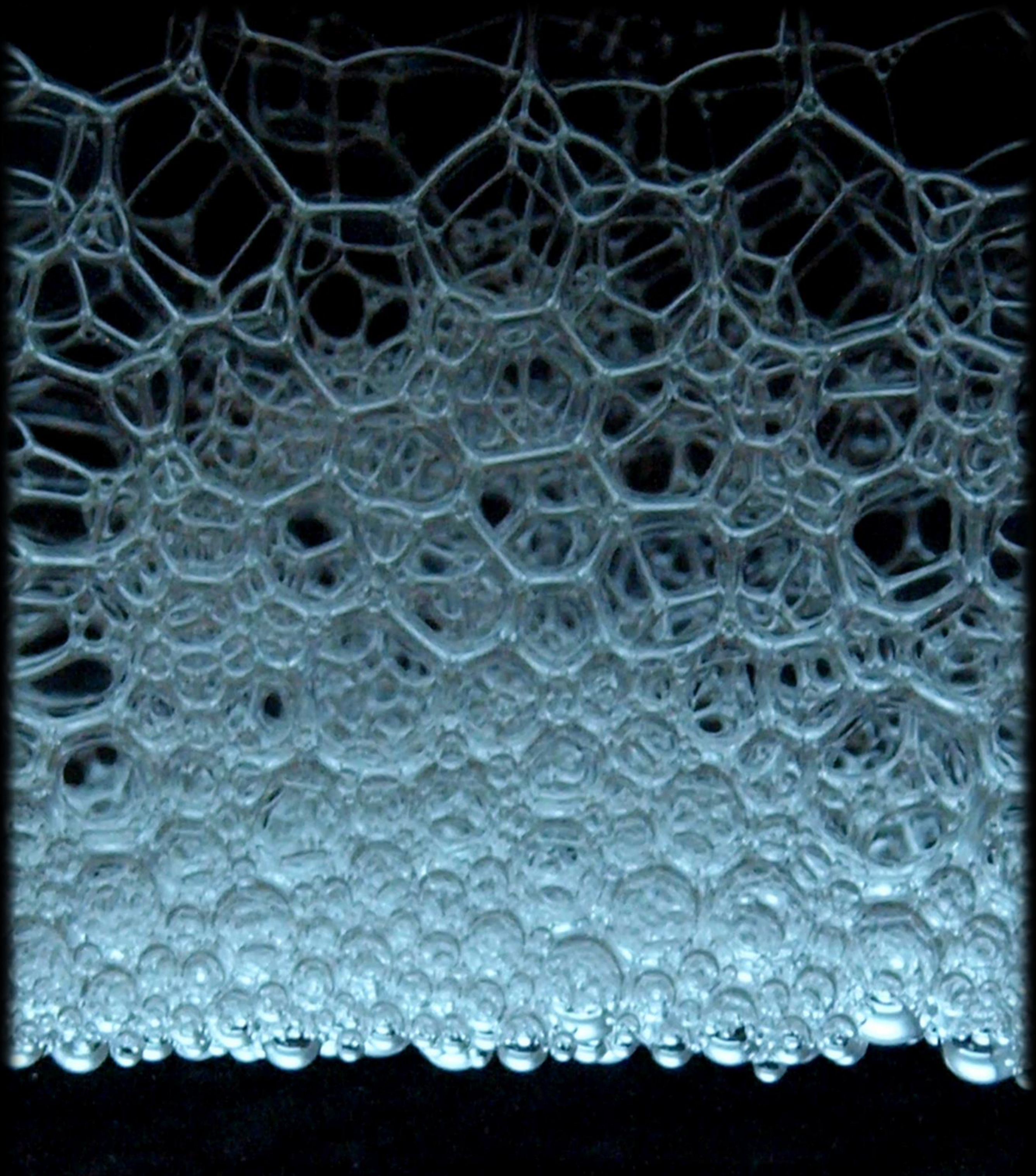
Les lois de Plateau



Pas si bordellique finalement !

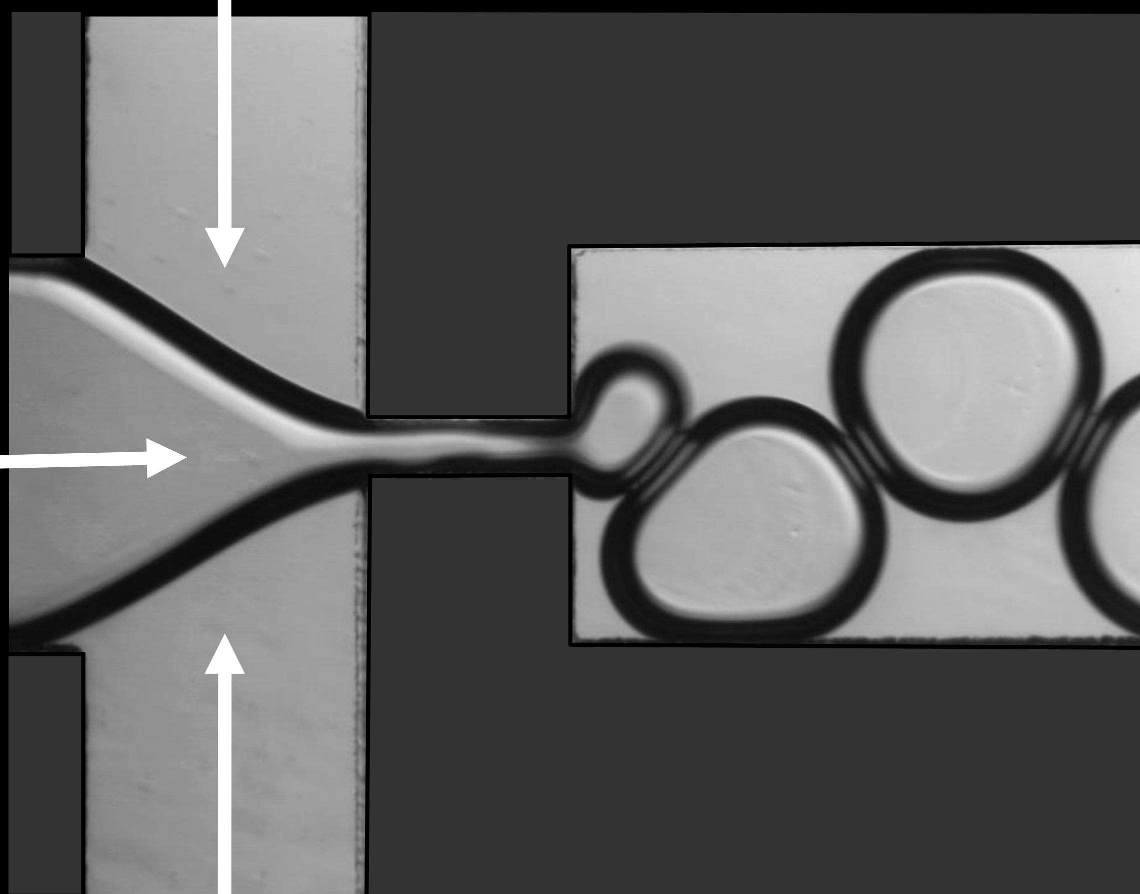


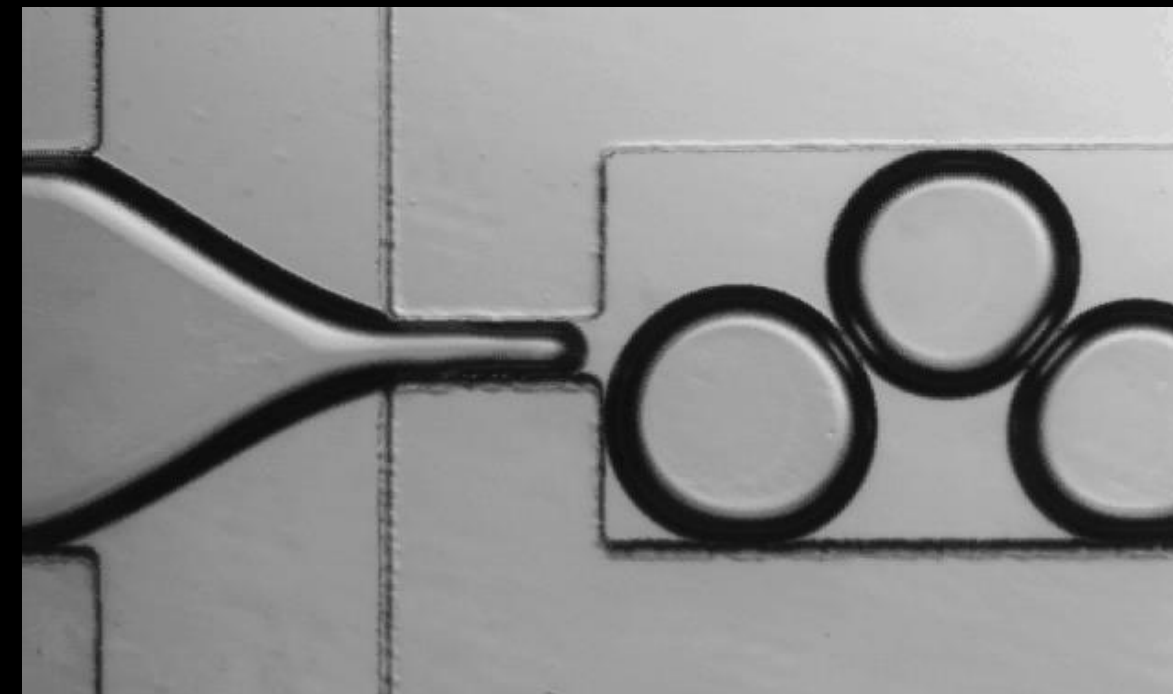
Dublin artist D. Boran



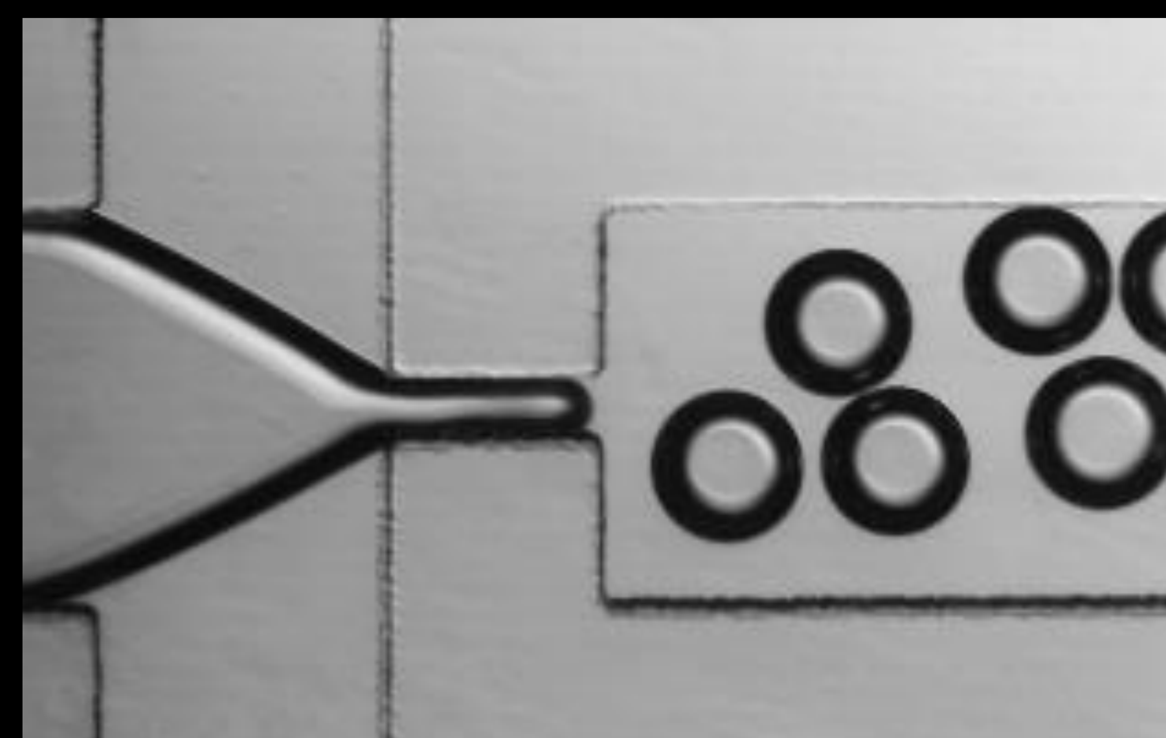
?

(Petite) machine a bulles

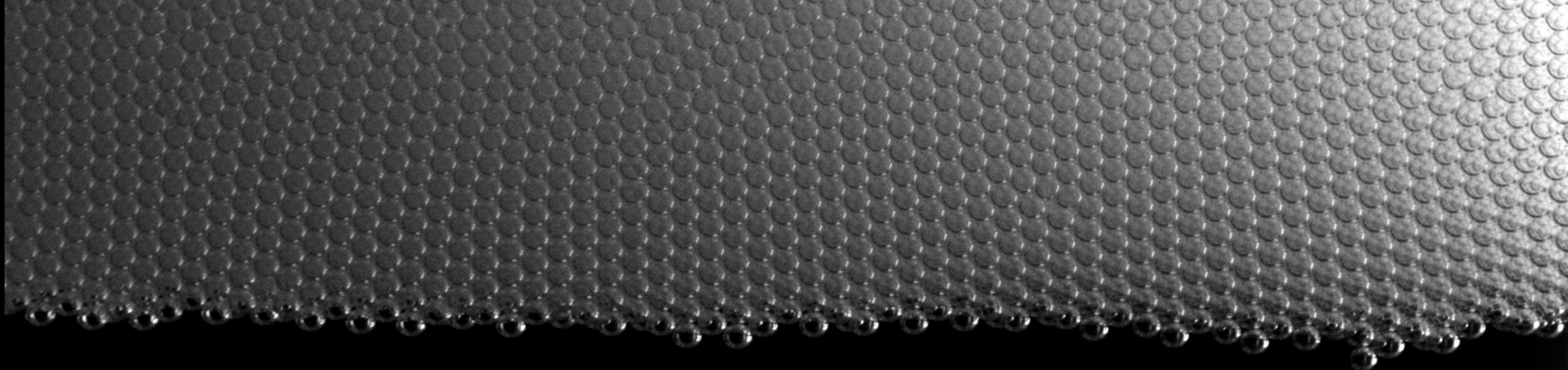


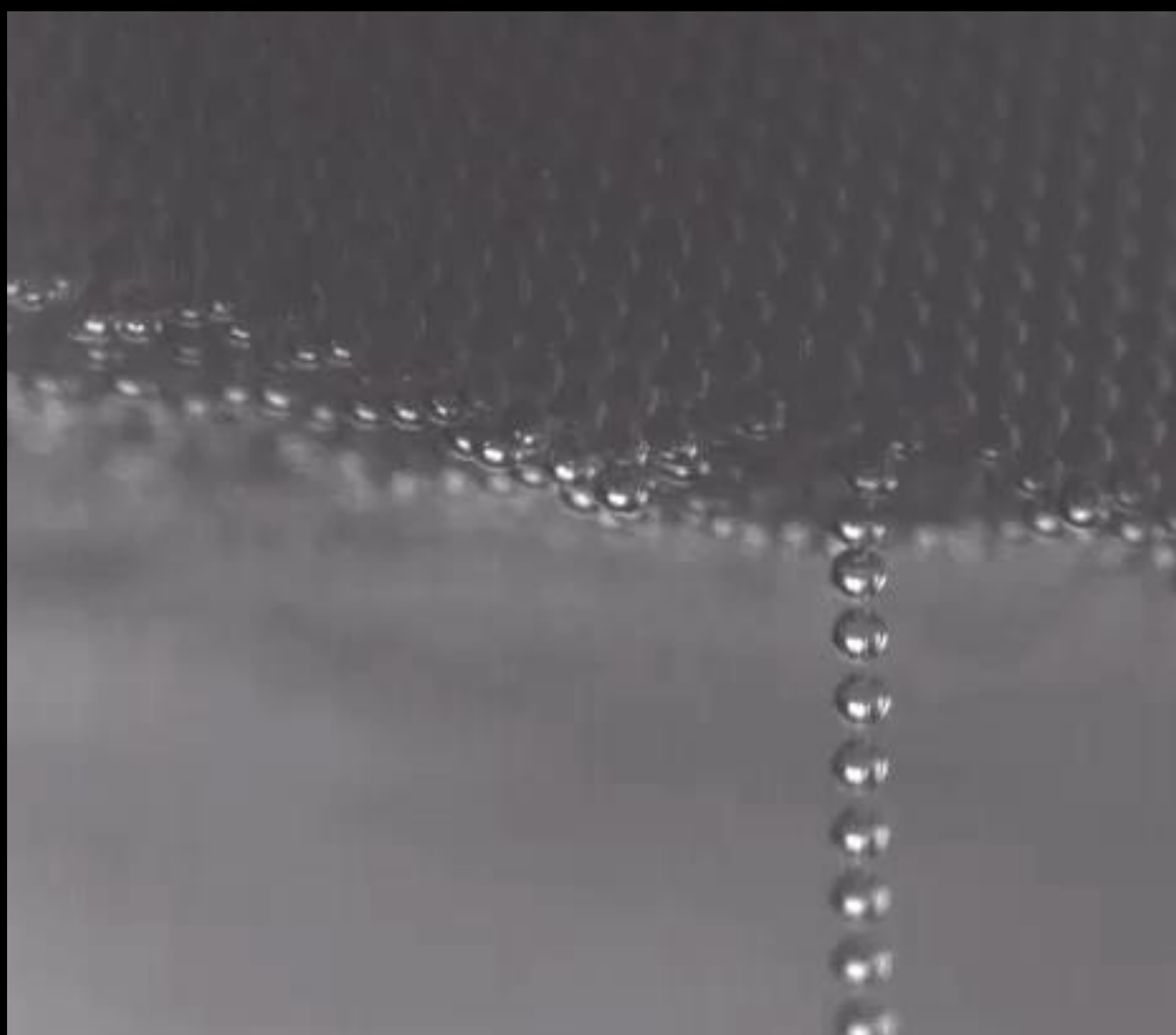


↓ Baisse du débit de gaz,
augmente le débit de la solution

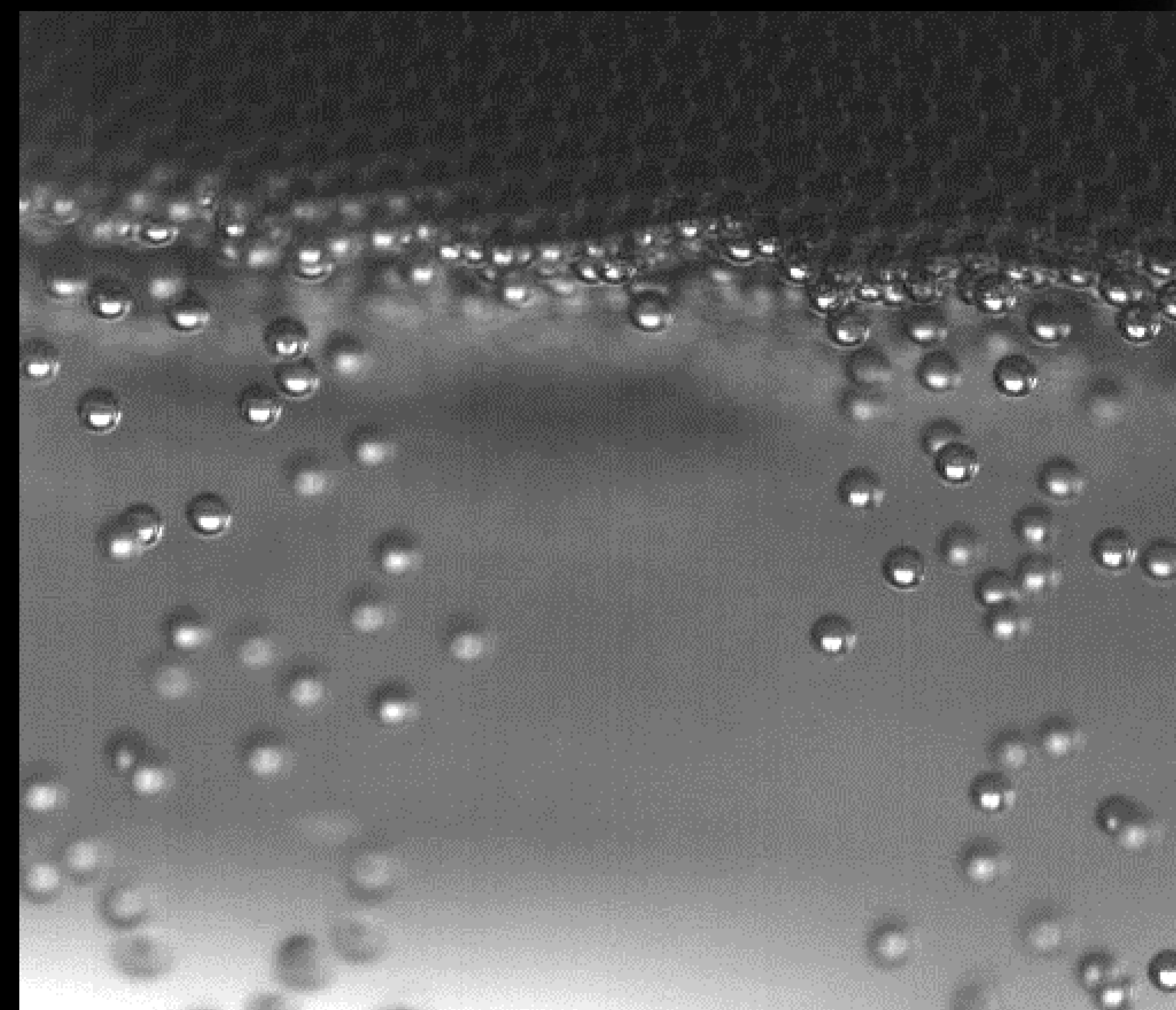


La “microfluidique”





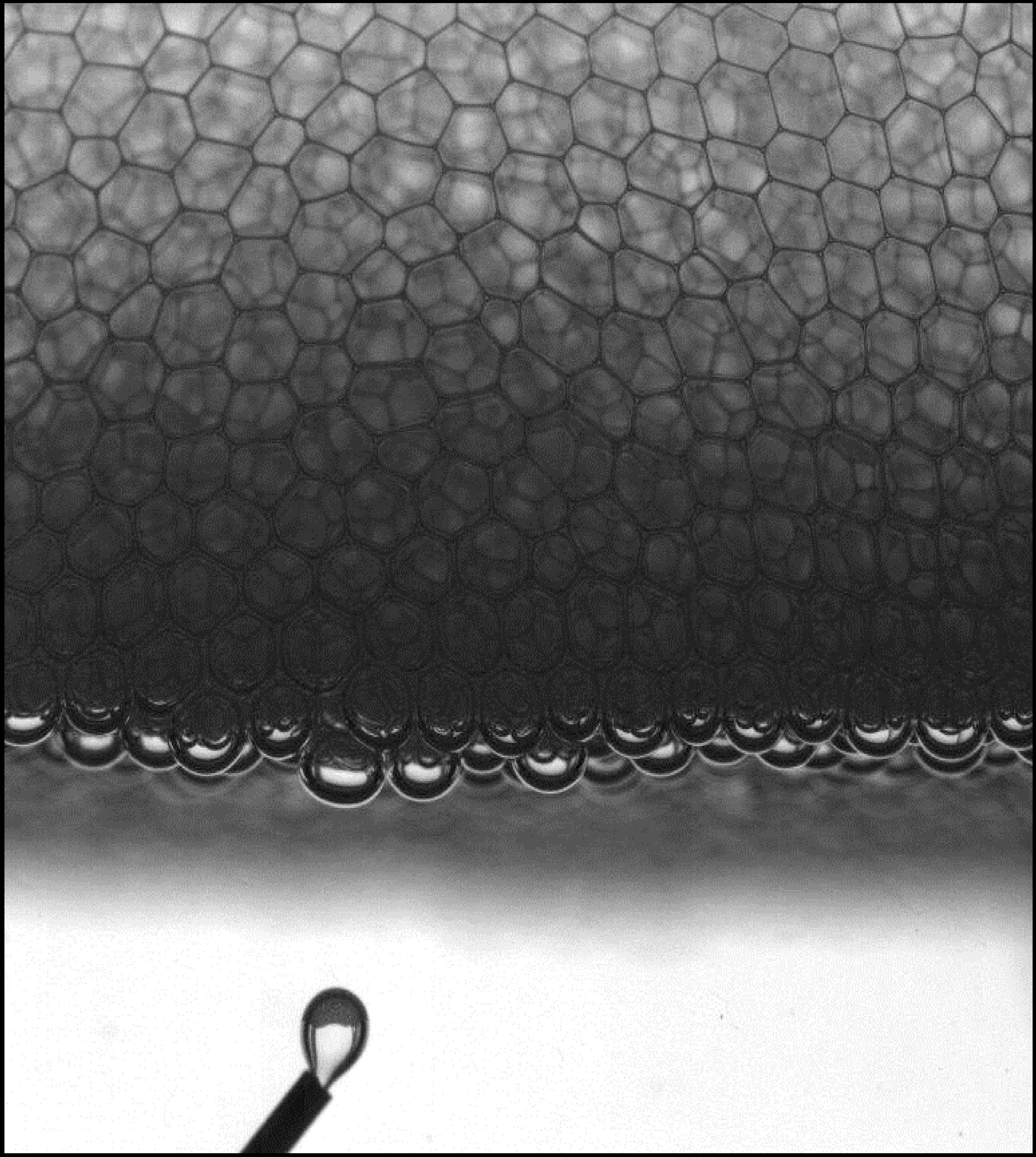
Ralenti 30 fois ...

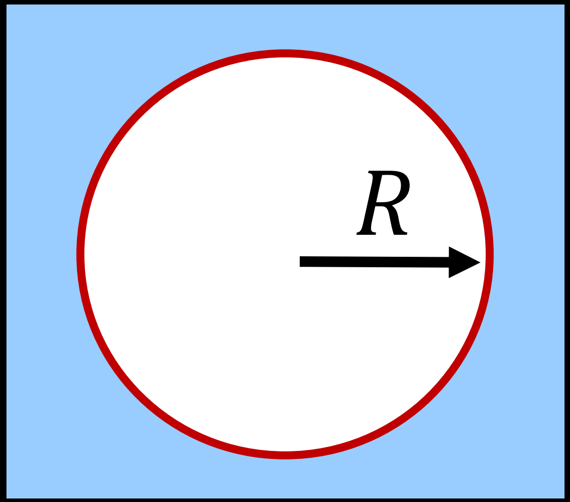


Ralenti 100 fois ...

Une bière de physicien(ne)s !

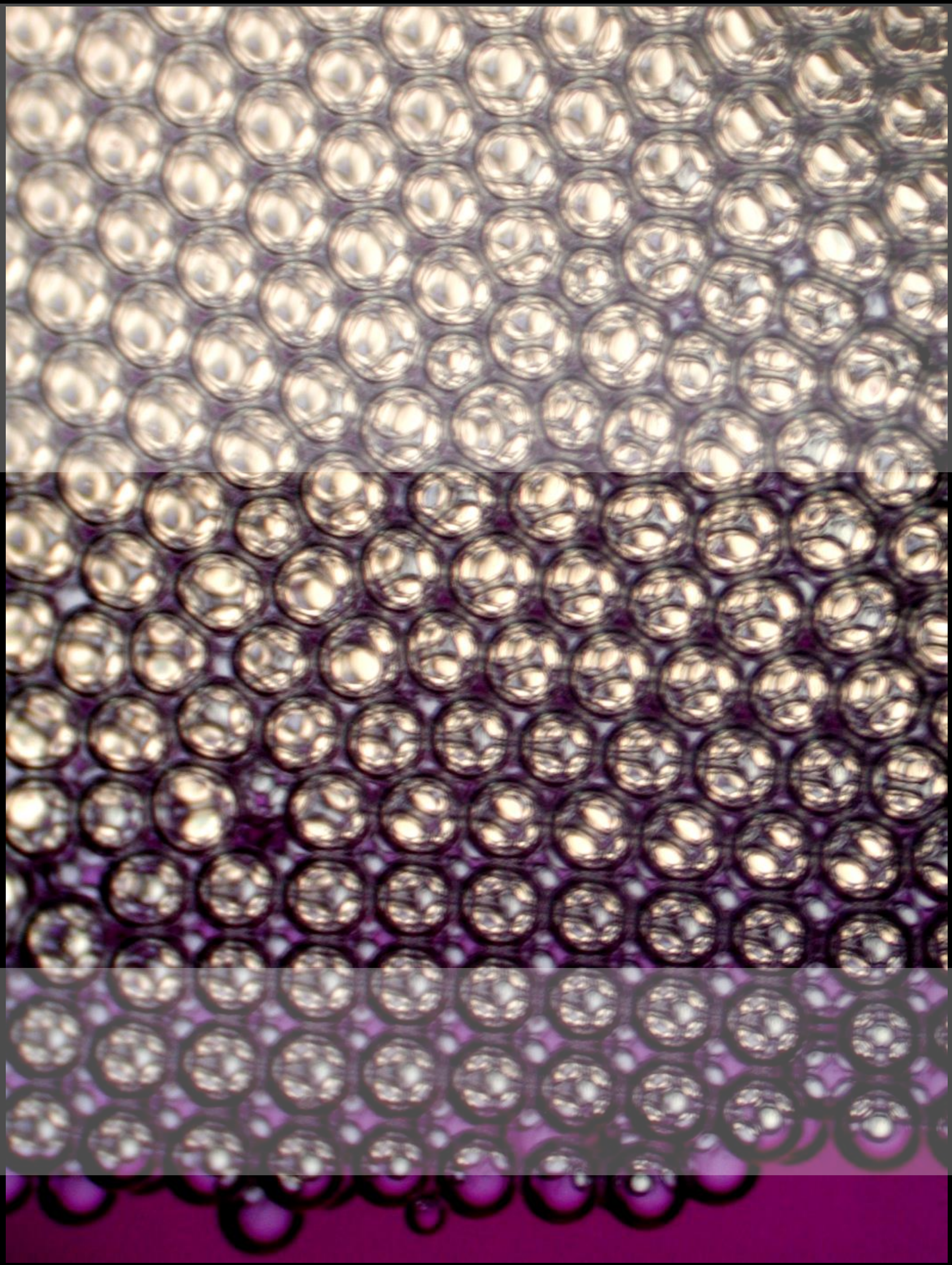
Des bulles plus grosses ?



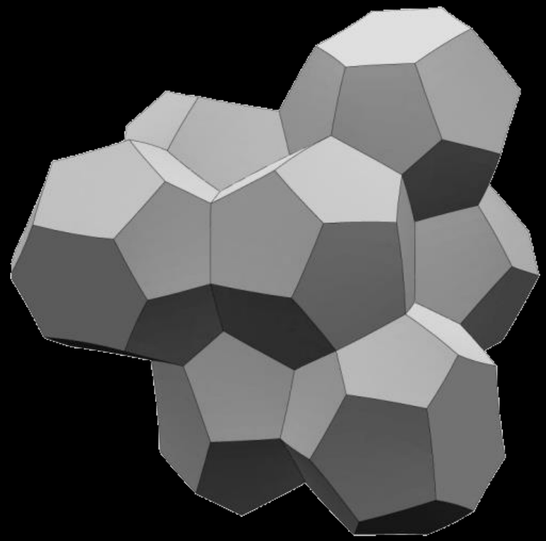


$$\Delta p = \frac{2\gamma}{R}$$

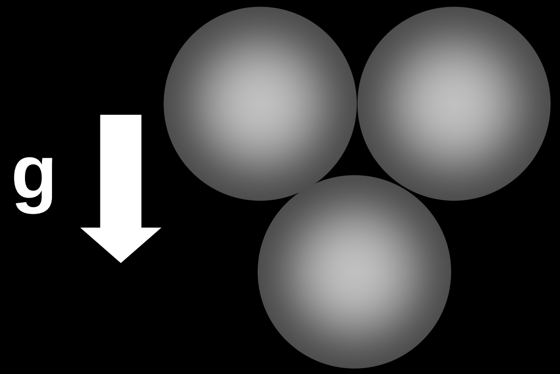
Pression plus faible
-> plus deformable
sous gravité



BULLES POLYHEDRALES

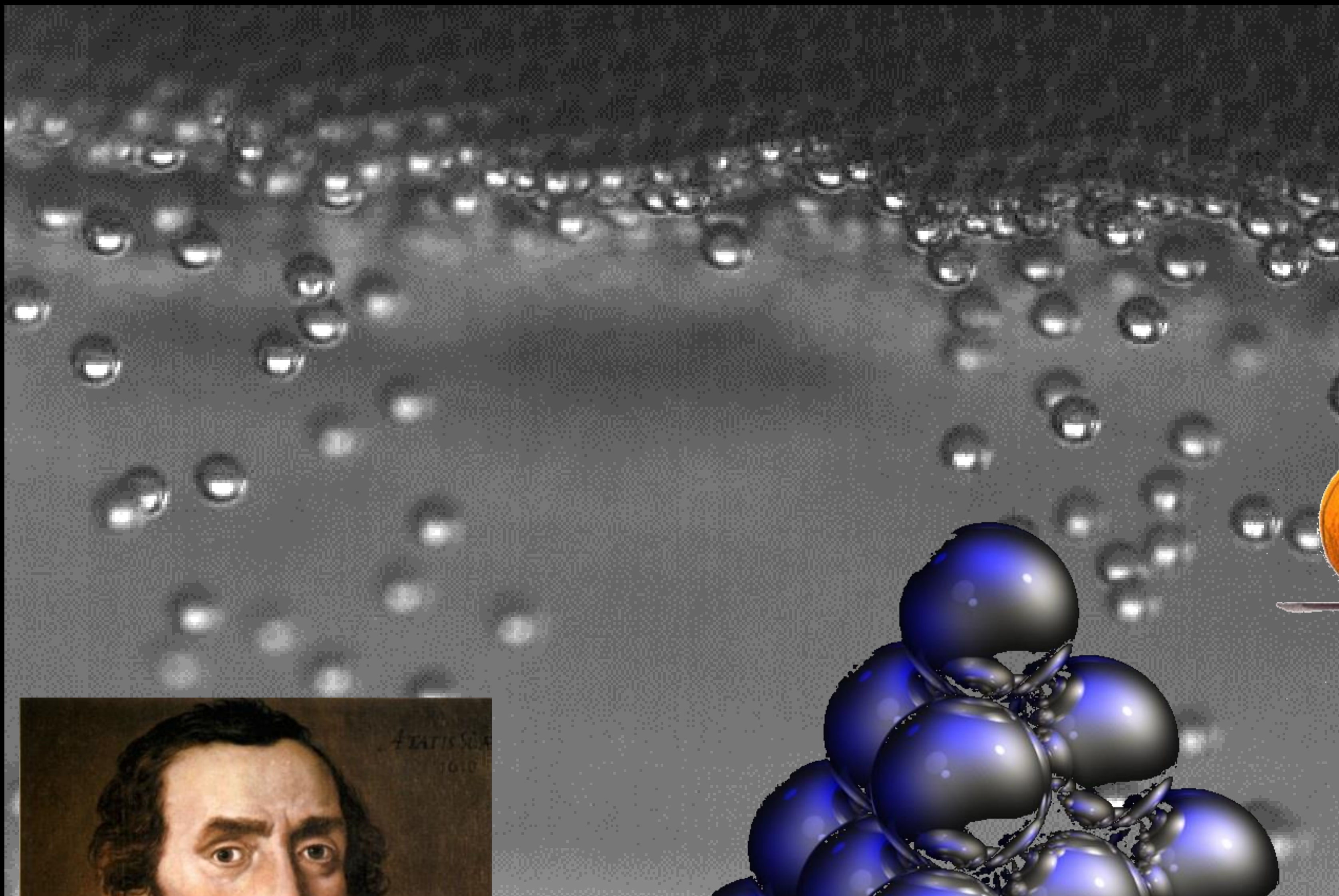


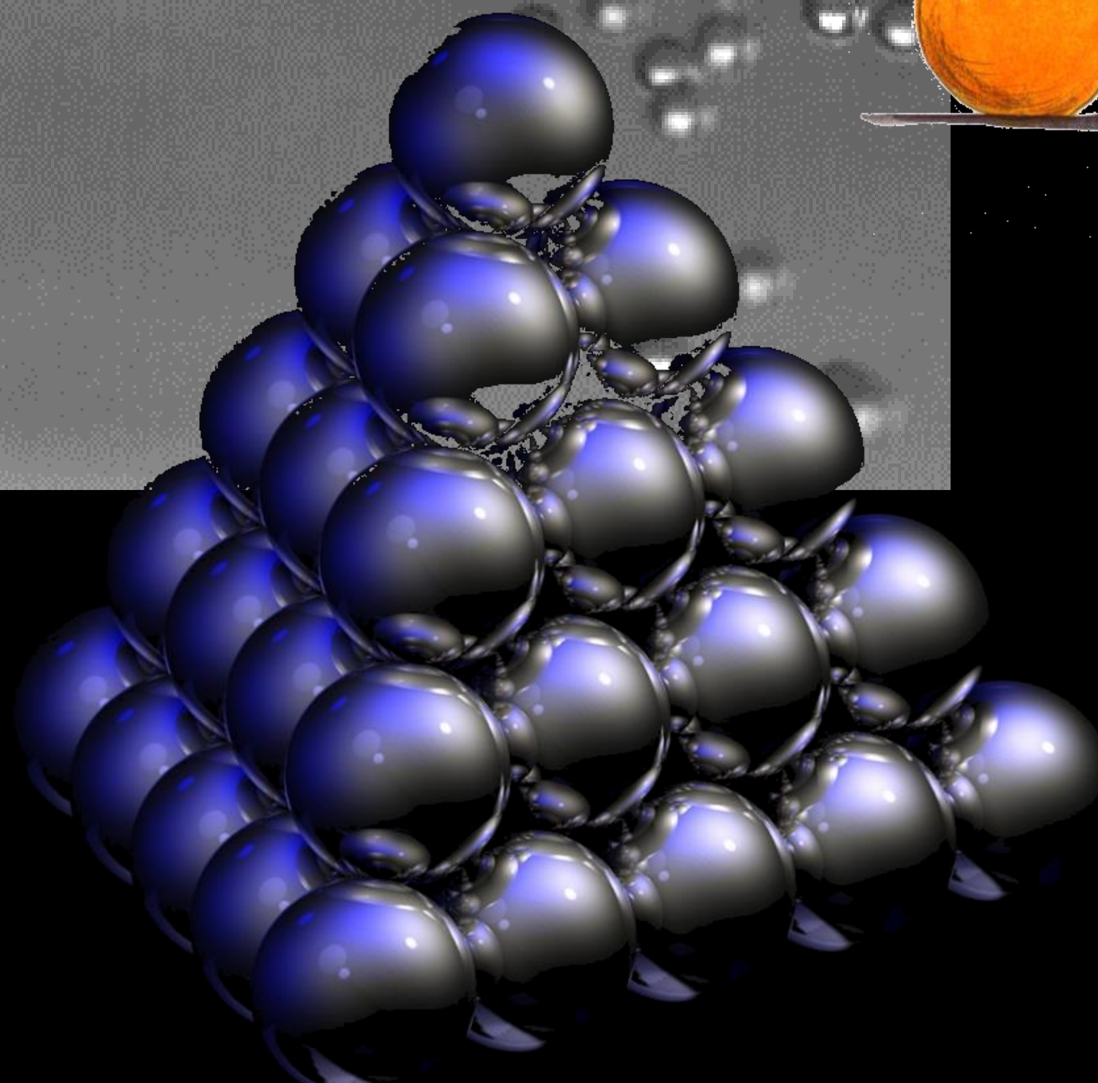
BULLES SPHERIQUES



DEUX PROBLEMES D'IMPILEMENT

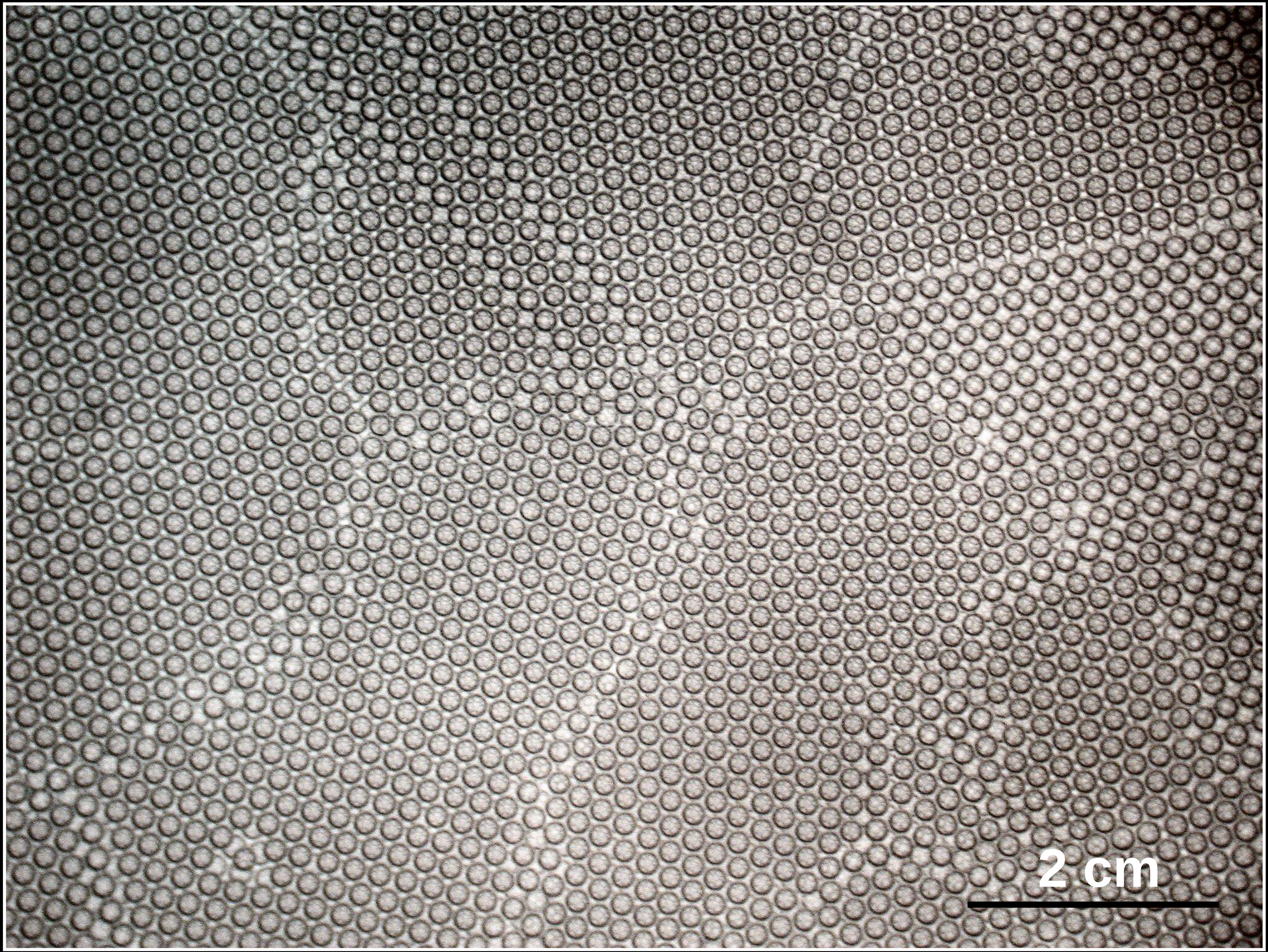
Quelle est la manière la plus compacte d’empiler des billes ?





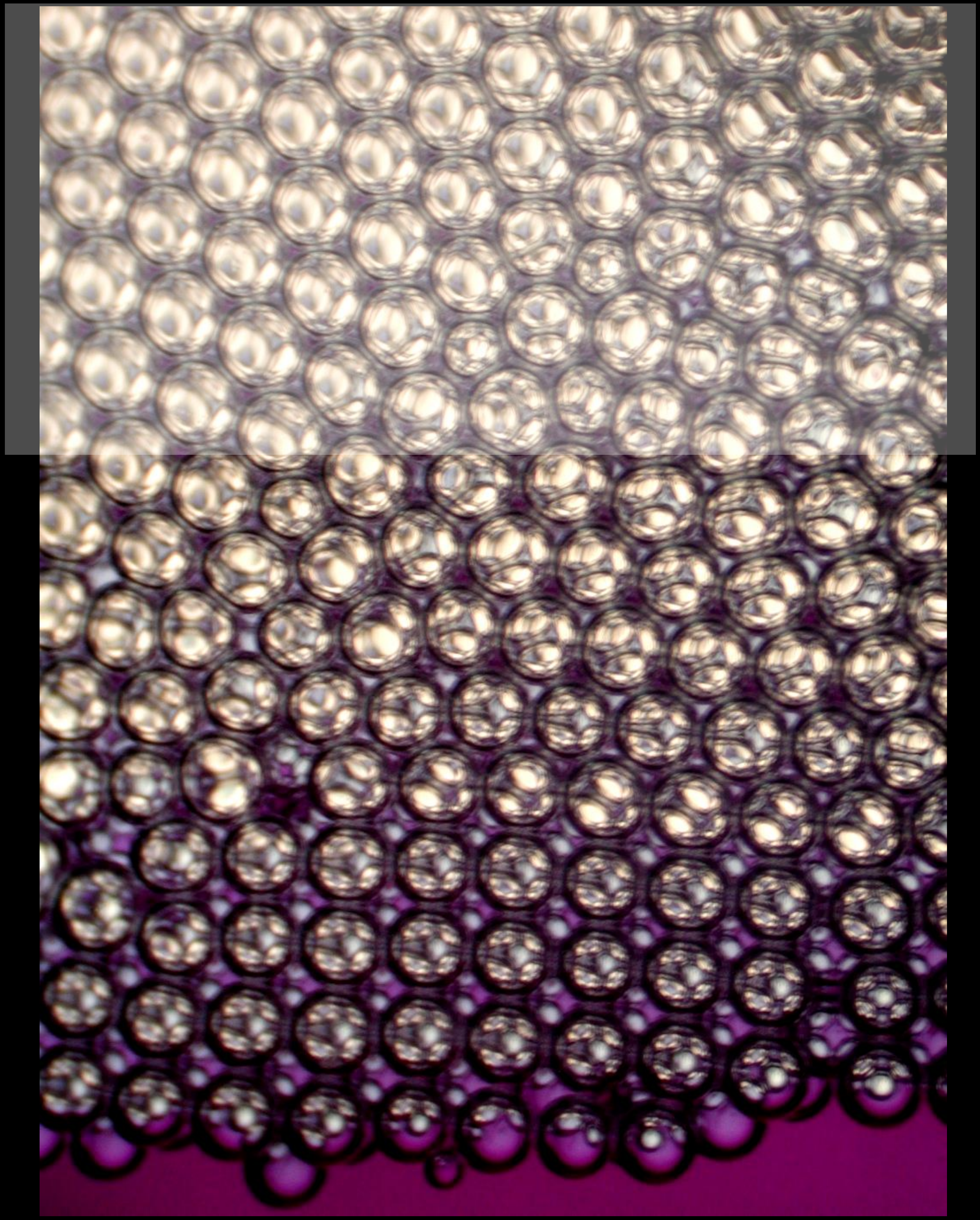
Conjecture de J. Kepler (1611)

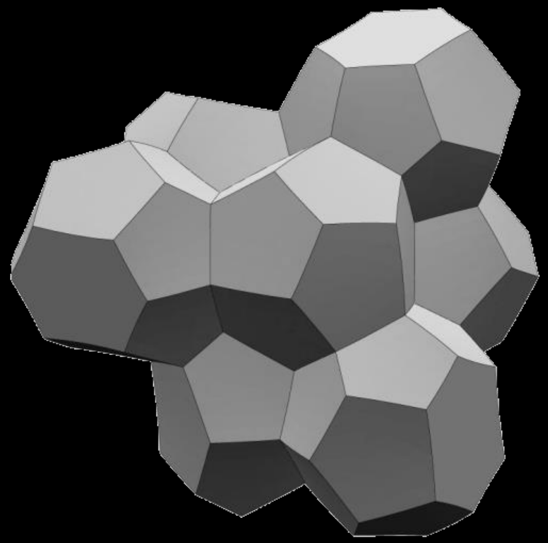
Preuve mathematique: T. Hales (2014)



Bragg, Nye (1947), V. der Net *et al.* (2006), Hoehler et al. (2007)

BULLES POLYHEDRALES

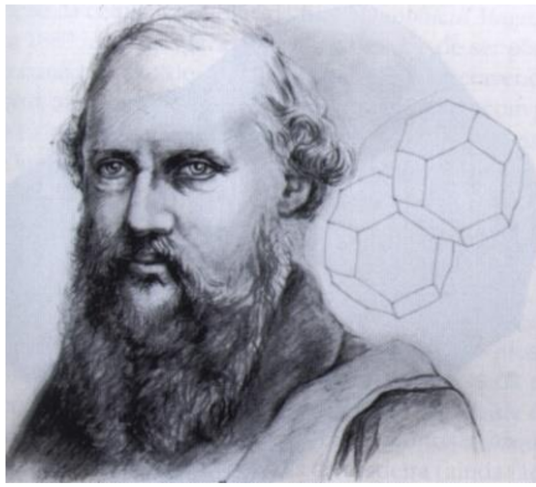


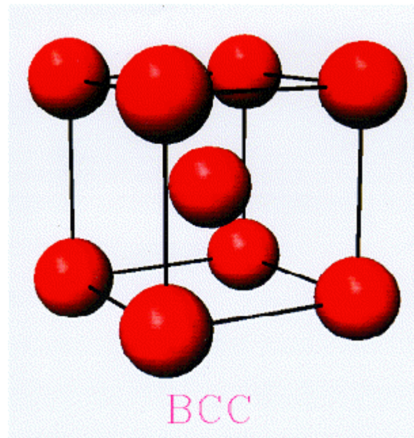


Quelle est la meilleur façon de deviser l’espace en volumes égales tout en minimisant l’interface crée entre les cellules ?

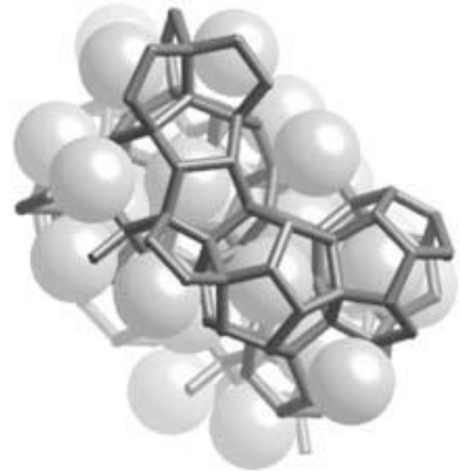
Le problème de Kelvin (1887)

1887





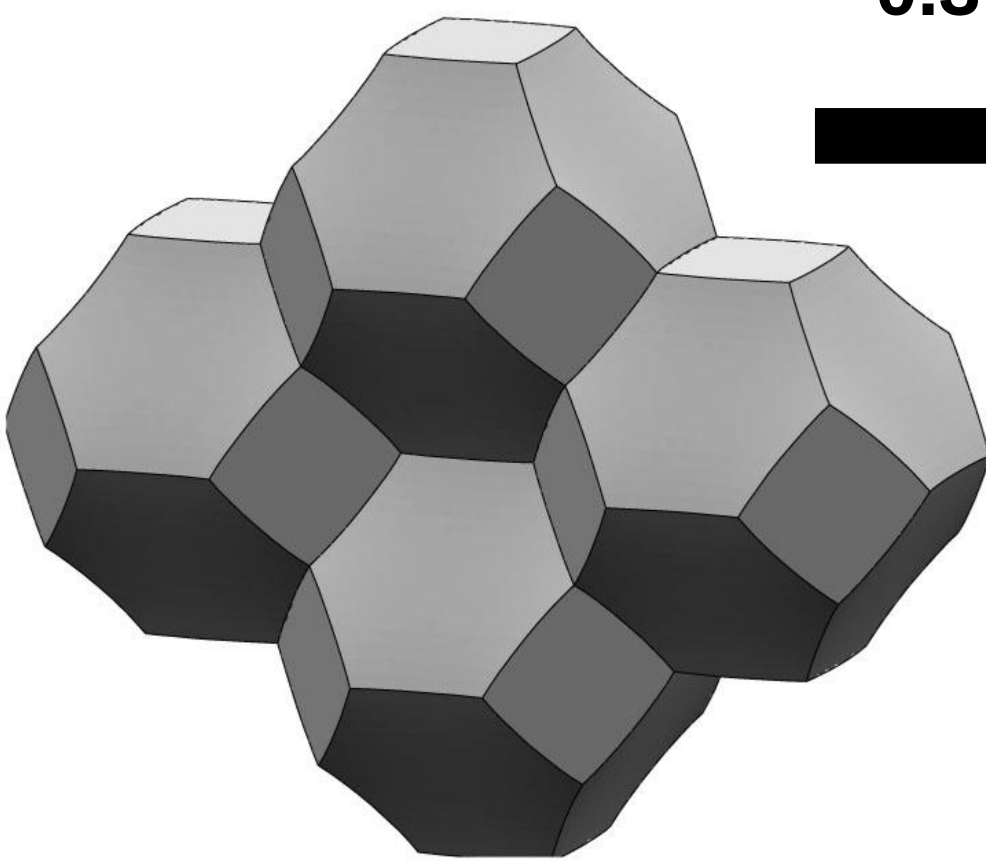
Clathrate, A15



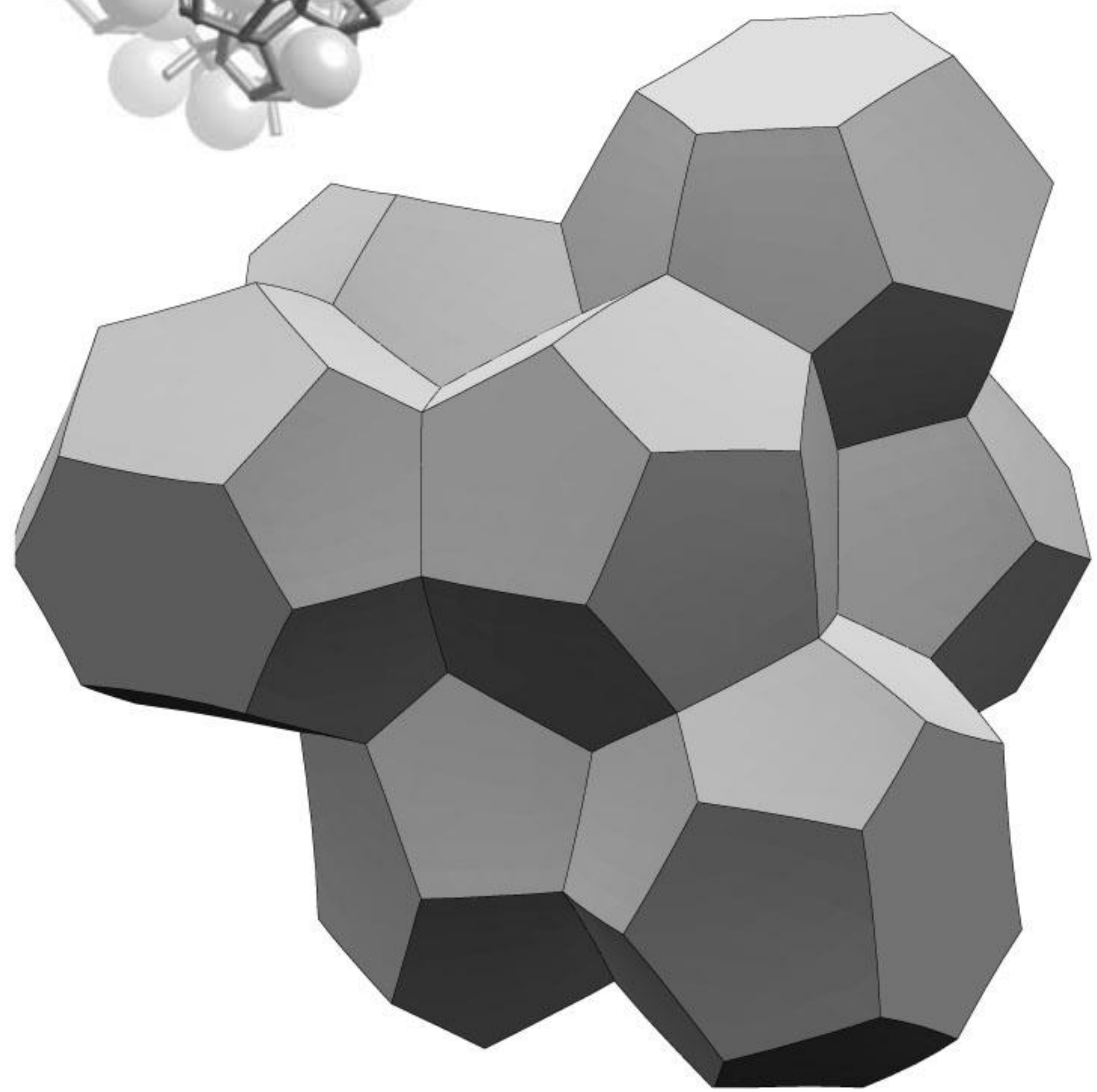
1994

1 Tetrakaidecahedron
3 Dodecahedrons

- 0.3 %



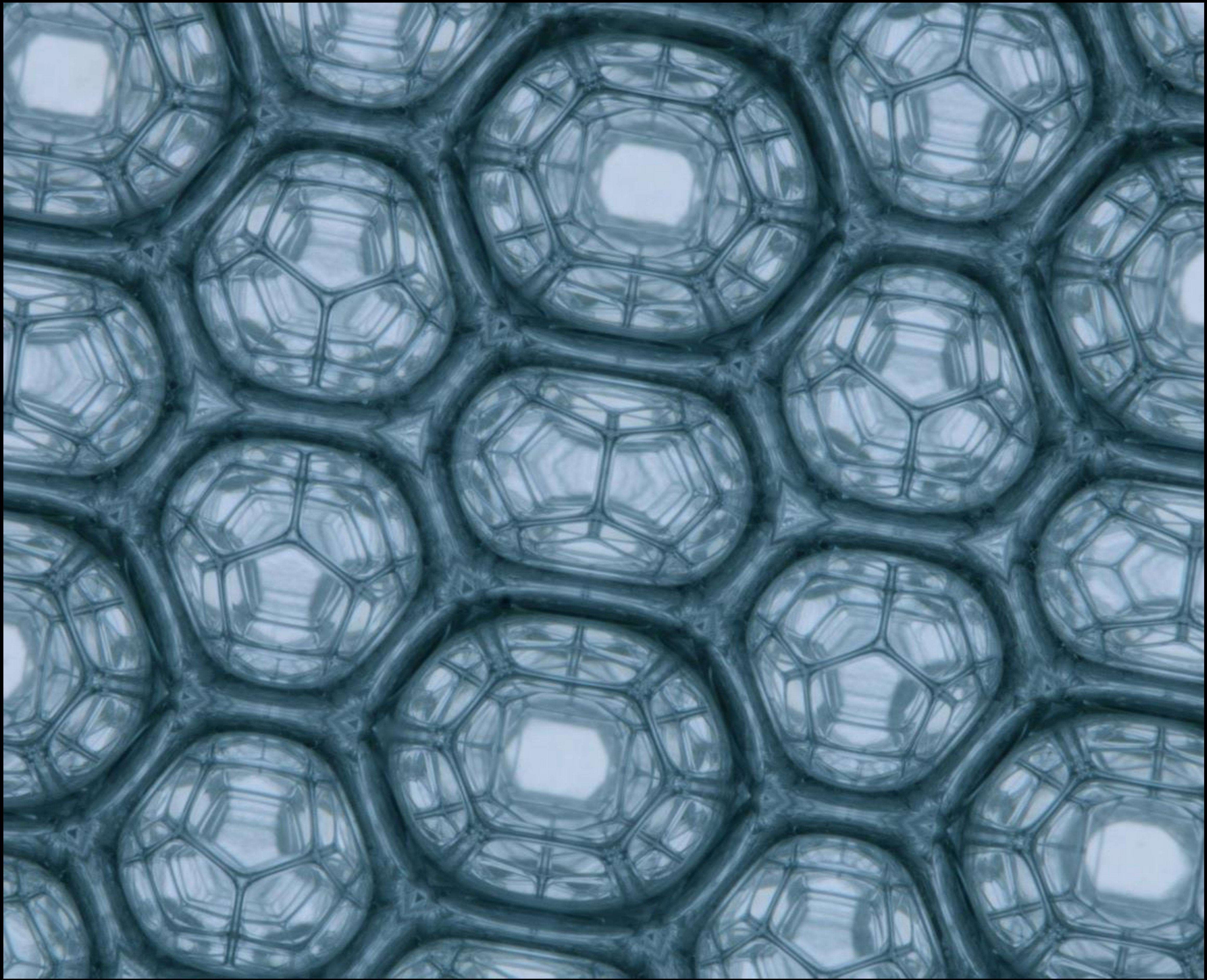
Cellule de Kelvin



Structure de Weaire-Phelan

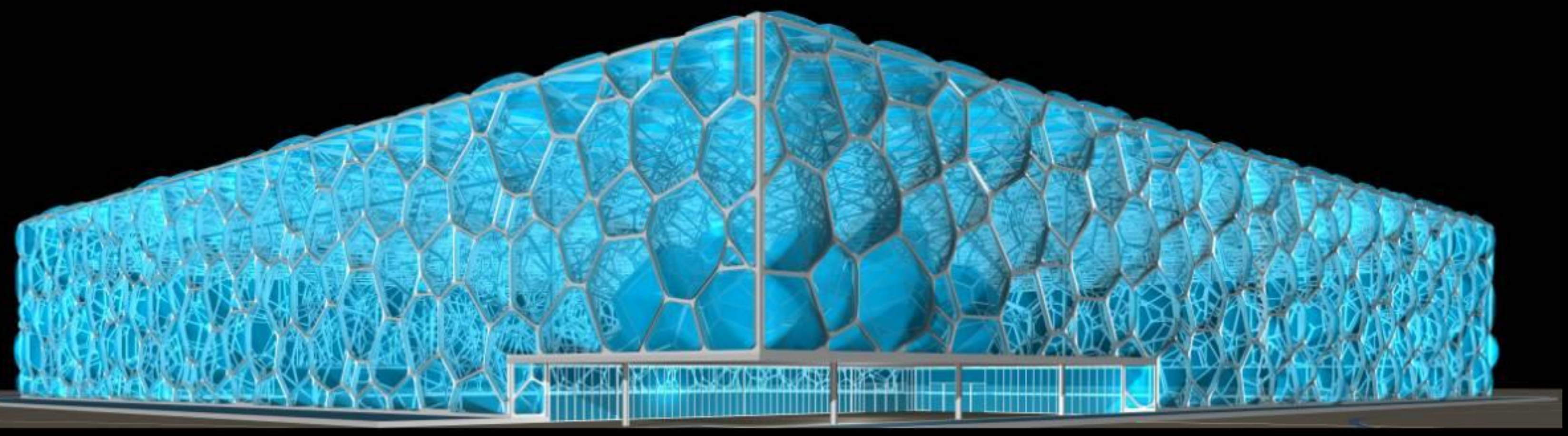
Hales :

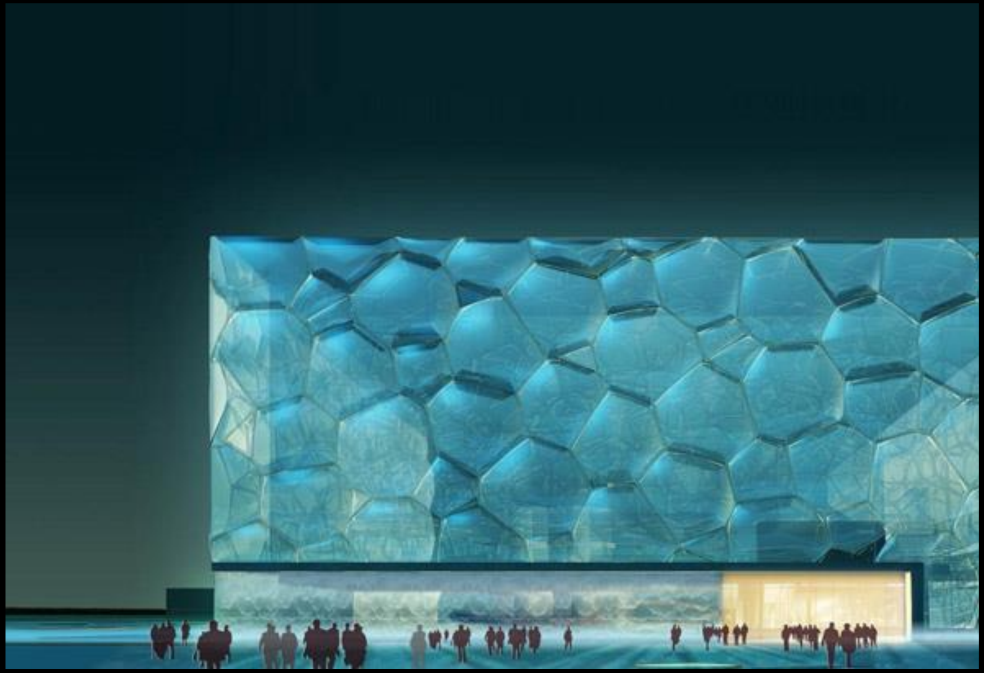
“Donnez moi 50 ans pour le prouver …. “

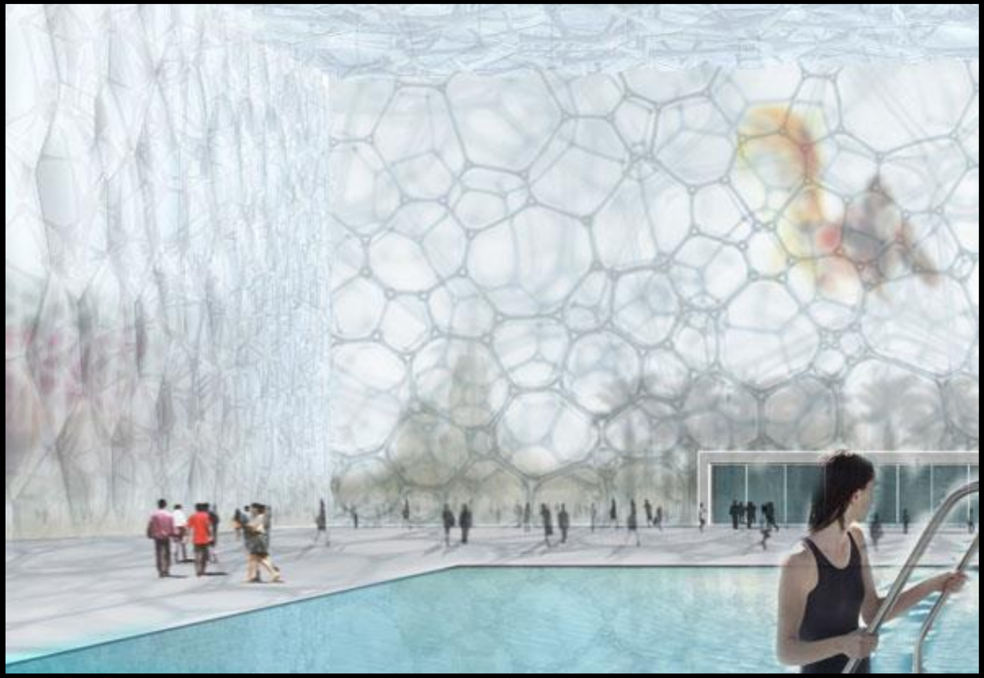


Gabrielli et al. (2011)

THE WATER CUBE
Olympic games Beijing 2008

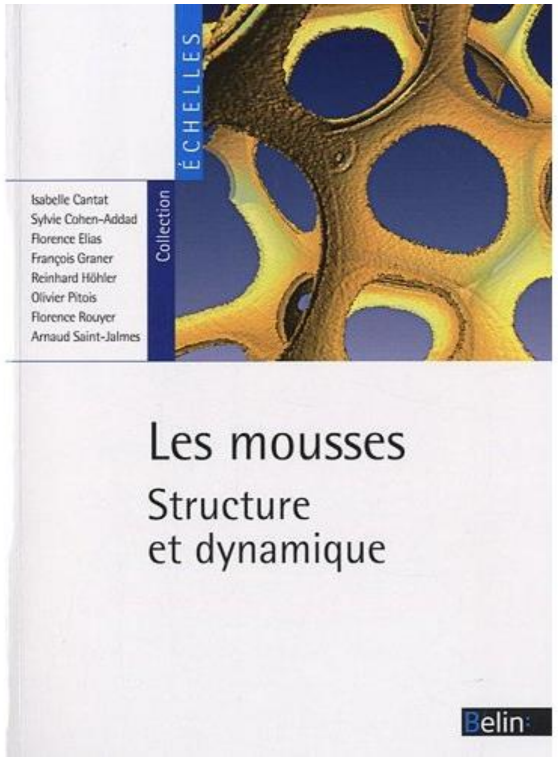


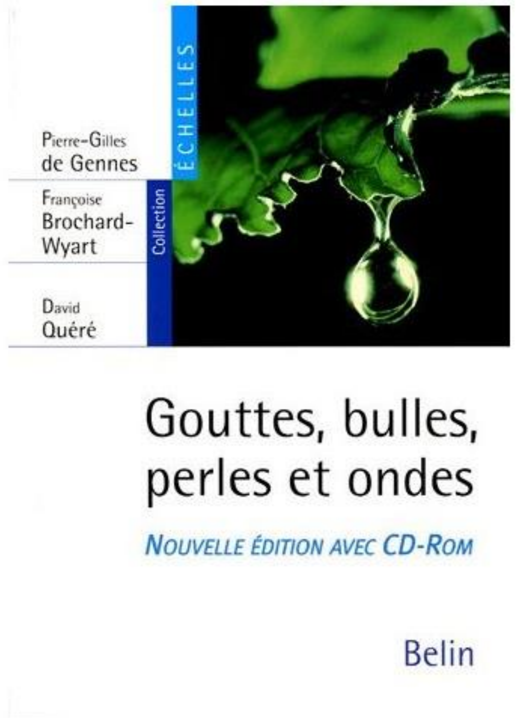




Un peu de lecture …

En Francais





En Anglais