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Soft matter approaches for food proteins: interfacial and foaming properties

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Stéphane Pezenec, Valérie Lechevalier-Datin. Soft matter approaches for food proteins: interfacial and foaming properties. STLOpen Days 2019, Mar 2019, Rennes, France. hal-02097222

HAL Id: hal-02097222

<https://hal.science/hal-02097222>

Submitted on 4 Jun 2020

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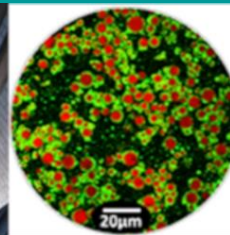
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Soft matter approaches for food proteins: interfacial and foaming properties



STLOpen Days
19-21 March 2019



Valérie Lechevalier & Stéphane Pezenec



Protein functionality

- relation of technological aptitudes to intrinsic features
- 'biochemical' viewpoint
(amino-acid composition, sequence, structure...)
- *colloidal* viewpoint
(size, charge, anisotropy, pressure, transport, concentration...)
- the two worlds meet at interfaces

Boire et al., 2019 ([doi:10/c3jt](https://doi.org/10.1016/j.c3jt))

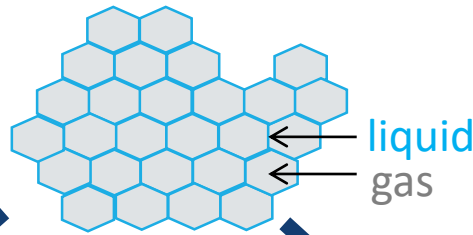
Interfacial properties of proteins

- proteins as surfactants: adsorption to hydrophobic interfaces
- irreversible adsorption
- unwanted consequences
(loss of enzymatic activity, fouling...)
- target effects: stabilization of dispersed systems
- our focus: air—water interface, foams

Outline

- approach & tools
- proteins at the air—water interface
- (interfacial) crowding
- properties of protein foams

Liquid foams are unstable systems



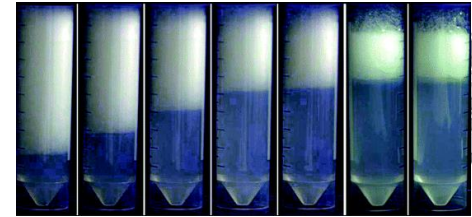
mechanical properties

low density

high specific area

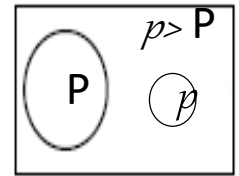
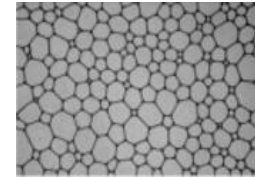
energy content: $A \cdot \sigma$

drainage



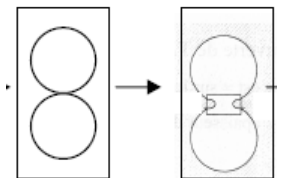
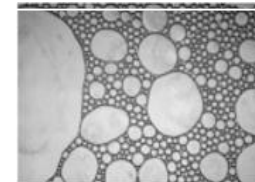
volume, liquid fraction \searrow

disproportionation



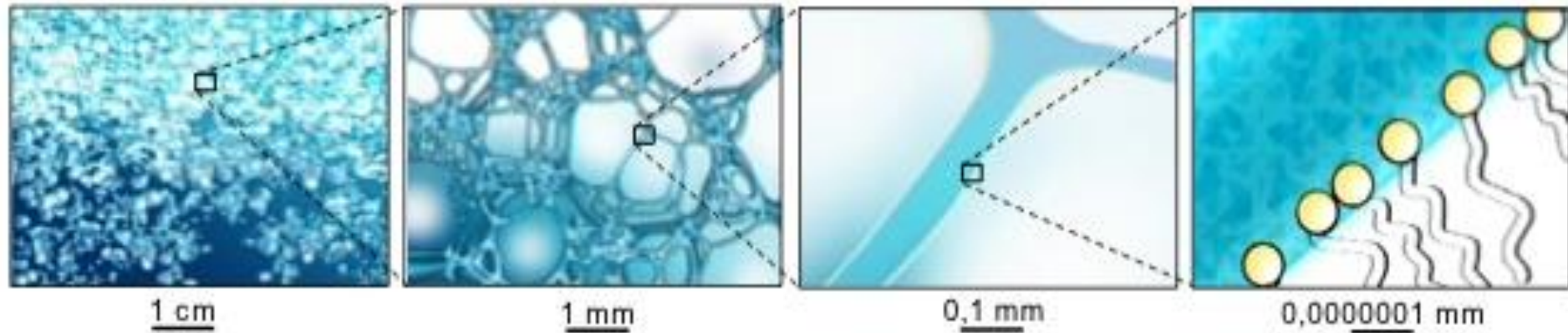
bubble size \nearrow

coalescence



bubble size \nearrow

Multiscale approach from foam to adsorption layer



foam: density, stability, rheology

bubble: size, shape, surface pressure

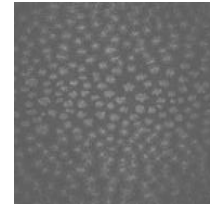
film: thickness, visco-elasticity, roughness

adsorption layer: adsorption kinetics, surface concentration, protein conformation and orientation, visco-elasticity, surface pressure

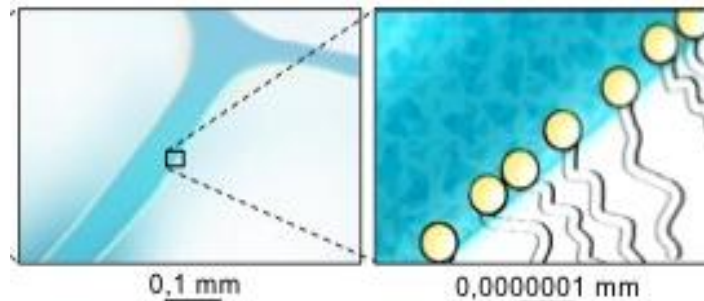
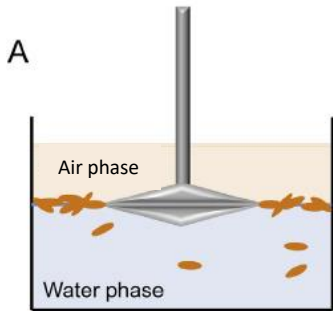
Interfacial measurements



Brewster angle microscopy
imaging ellipsometry

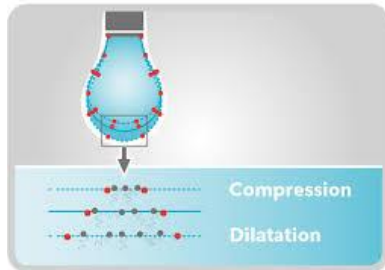


surface tension
shear rheology

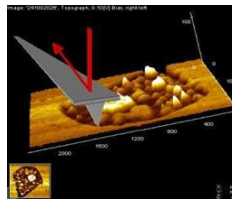


PM-IRRAS
molecular
conformation and
orientation

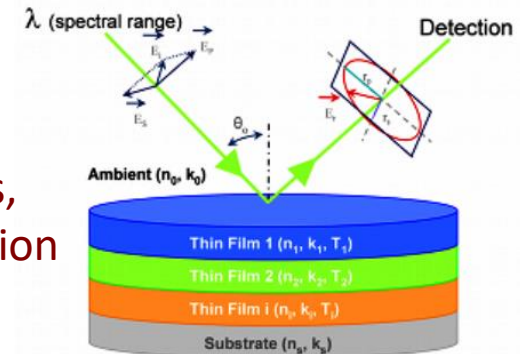
dilatational rheology



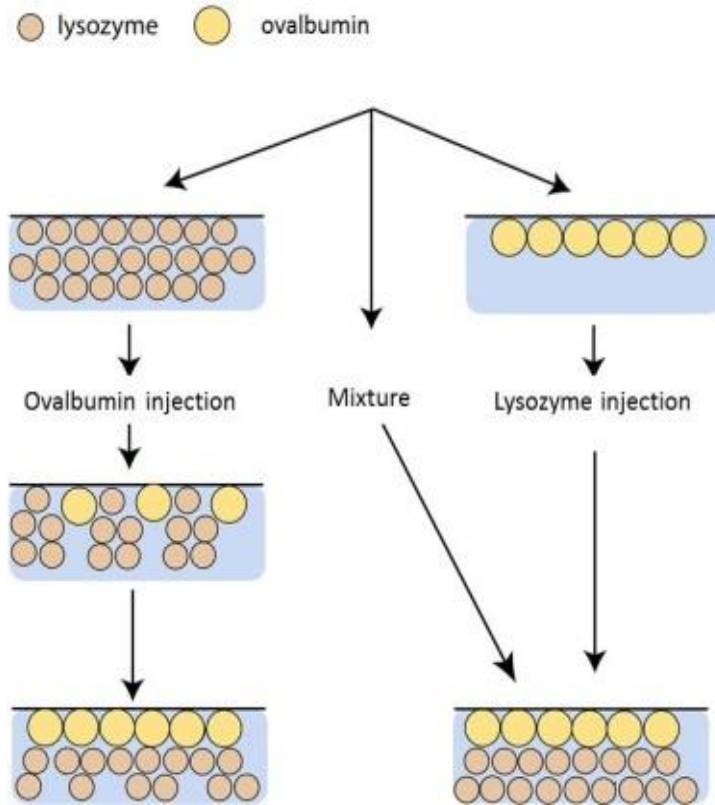
atomic force
microscopy
film thickness &
roughness



ellipsometry
adsorption kinetics,
surface concentration
excess



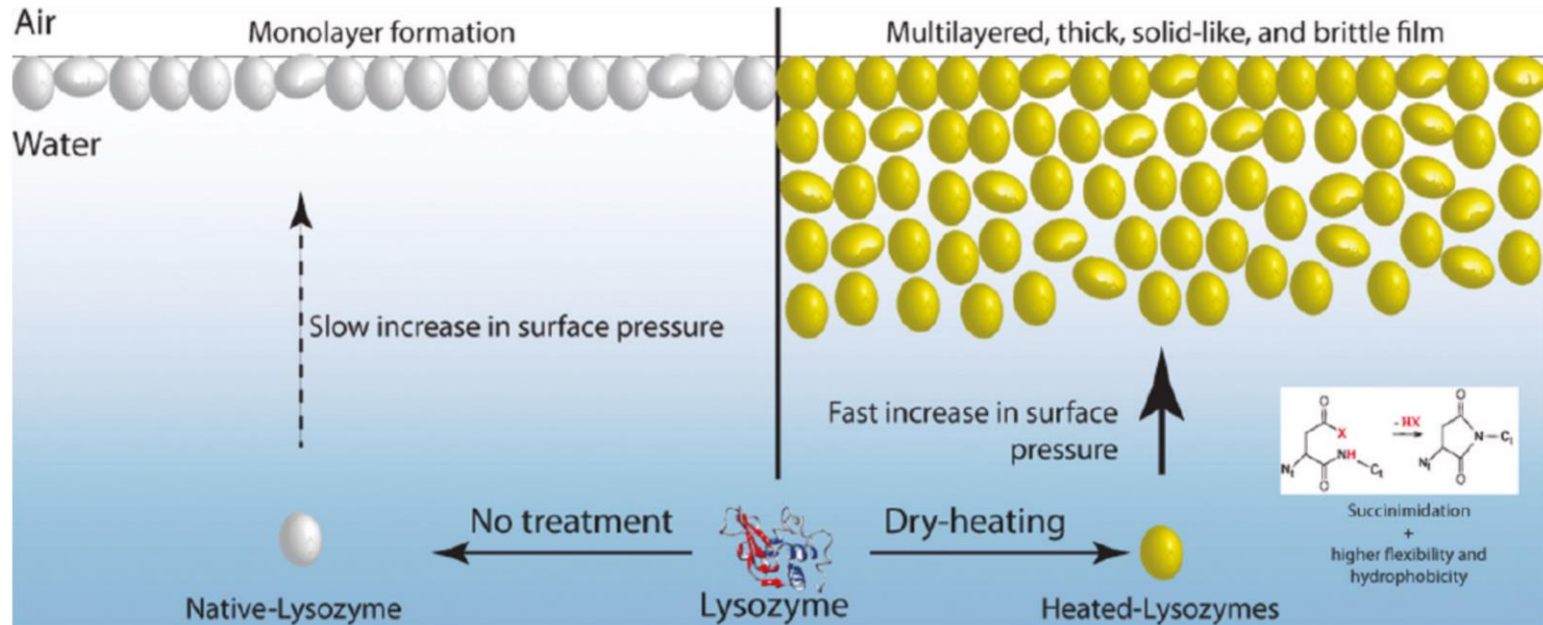
Interface as a competitive site for protein adsorption



- synergistic co-adsorption
- preferential protein assembly at the air-water interface
- stratified model, surface activity

Le Floch-Fouéré et al., 2009 ([doi:10/fxdc22](https://doi.org/10/fxdc22)), 2010 ([doi:10/d38gsz](https://doi.org/10/d38gsz))

Interface as an indicator of the changes in protein conformation



- minor changes in the protein stability dramatically impact the interfacial behavior
- dry-heating increases aggregation and propensity to self-association at the interface

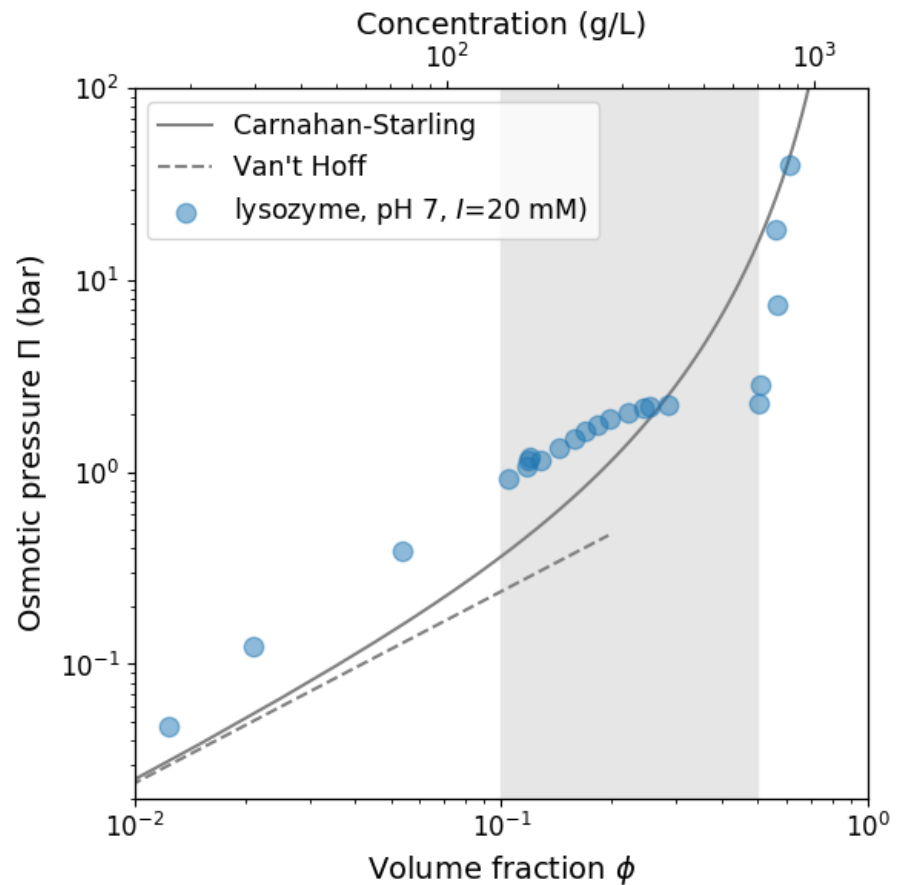
Desfougères et al., 2008 (doi:10/ck4w63), 2011 (doi:10/bfb25m)

Interface as a crowded system

- high local concentration in the interfacial film
- which contribution of crowding?
- osmotic pressure in concentrated solutions?

Interface as a crowded system

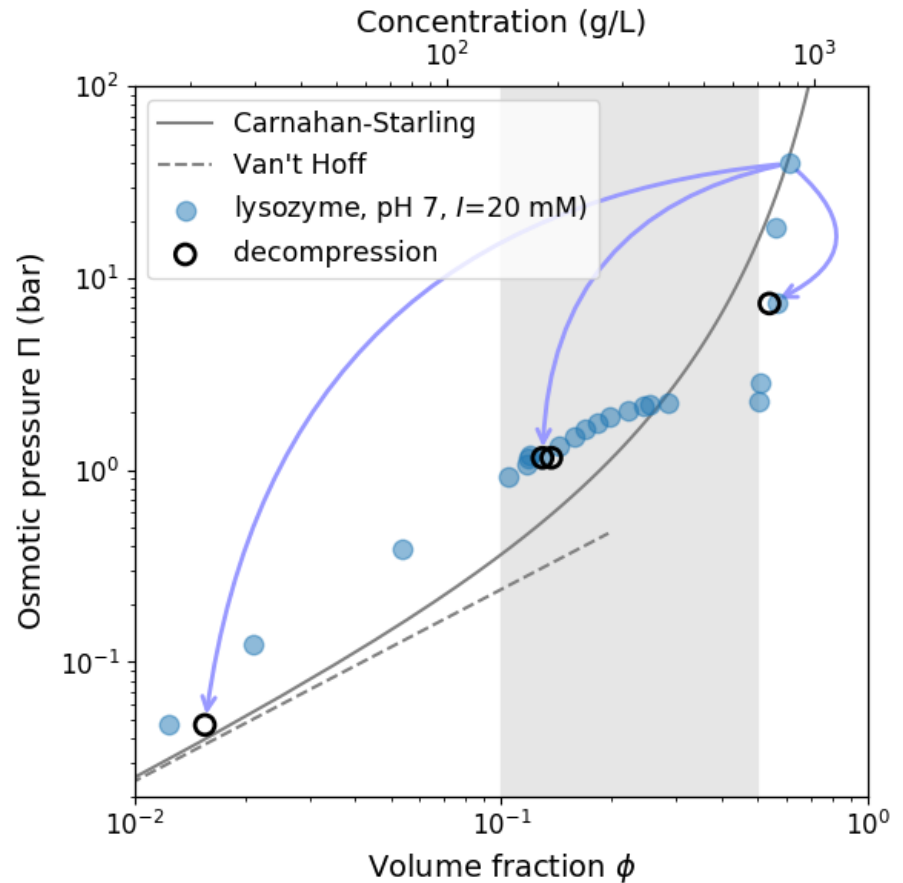
- phase transition: crystallisation



Pasquier et al., 2016 ([doi:10/bqqrz](https://doi.org/10/bqqrz))

Interface as a crowded system

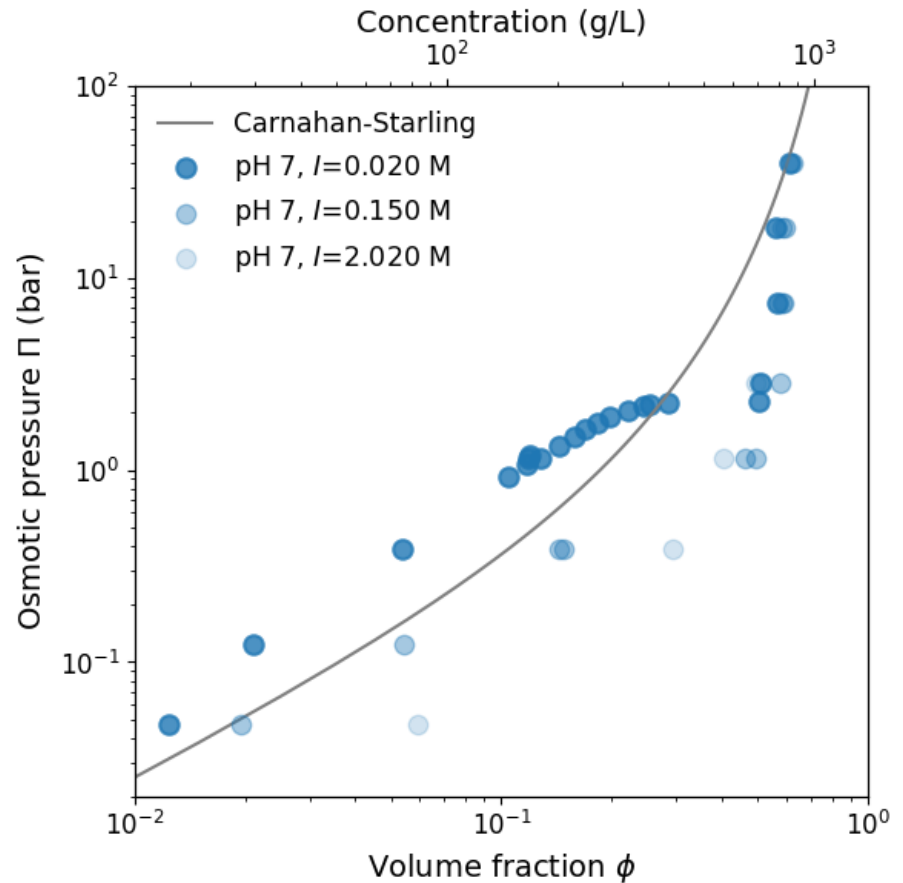
- phase transition: crystallisation
- reversibility, therm. equilibrium



Pasquier et al., 2016 ([doi:10/bqqrz](https://doi.org/10/bqqrz))

Interface as a crowded system

- phase transition: crystallisation
- reversibility, therm. equilibrium
- electrostatic interactions



Pasquier et al., 2016 ([doi:10/bqqrz](https://doi.org/10/bqqrz))

Interface as a crowded system

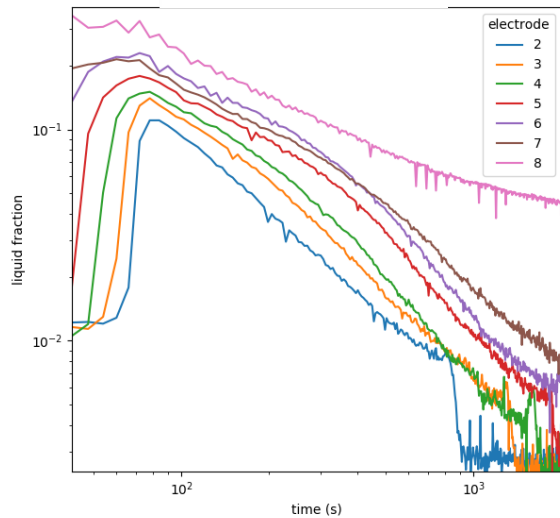
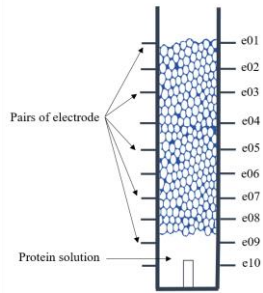
- correlation between EOS and interfacial behavior
- coupling between osmotic pressure gradients and transport
- advection
- ionic effects

From the interface to the foam

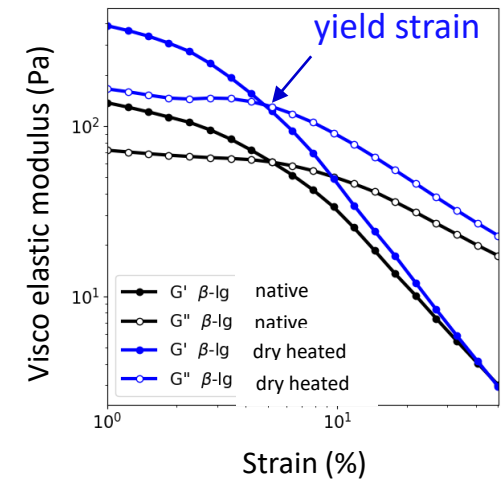
- relation of foaming properties to interfacial behavior?

Foam measurements

liquid volume fraction, drainage



foam rheology

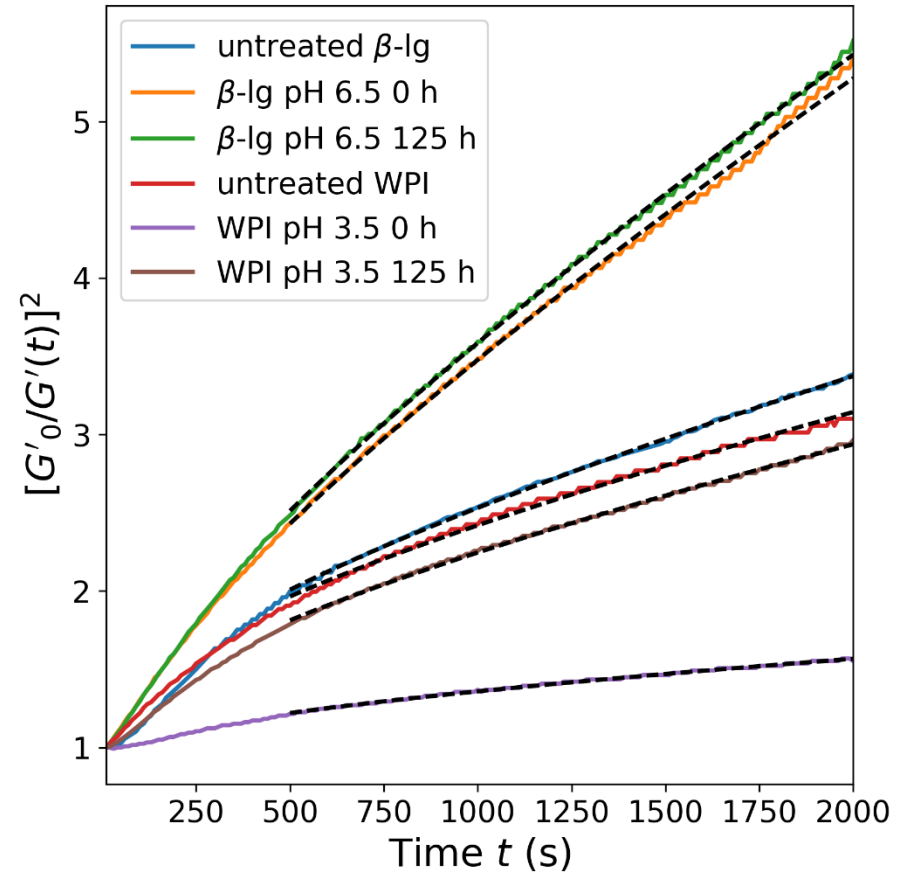


disproportionation

Audebert et al., 2019a ([doi:10/ctf8](https://doi.org/10.1016/j.cjfood.2019.04.008)), 2019b ([doi:10/cz9w](https://doi.org/10.1016/j.cjfood.2019.04.009))

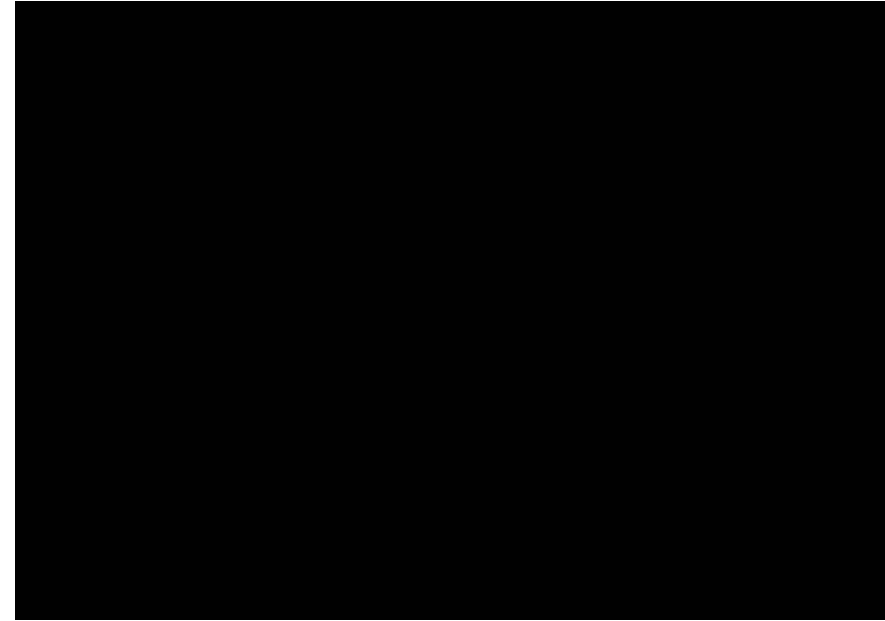
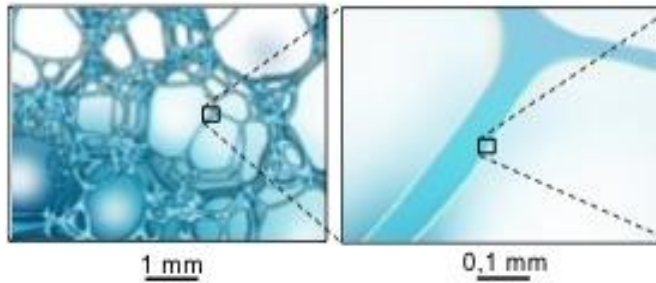
Foam rheology & disproportionation

- $G' = \frac{\sigma}{R} g(\Phi_l)$
- $R \sim \sqrt{t}$

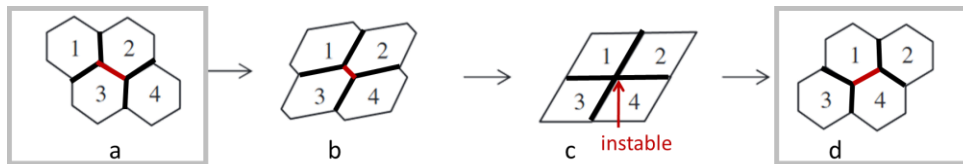


Audebert et al., 2019b ([doi:10/cz9w](https://doi.org/10.1016/j.cj.2019.03.001))

Bubble film dynamics

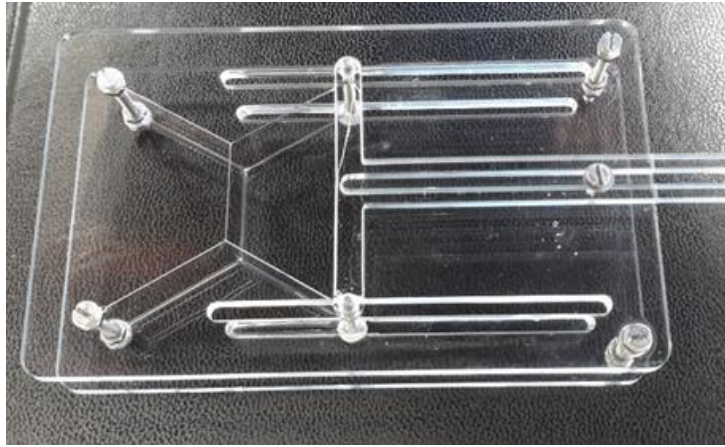


T1 topological rearrangements

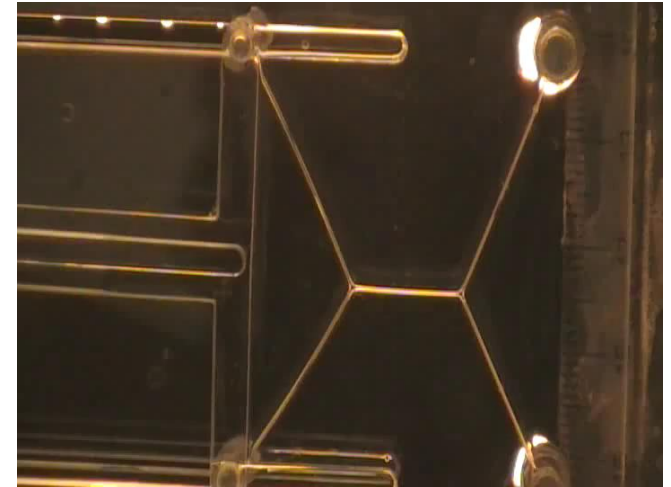


Krüß GmbH

Bubble film dynamics



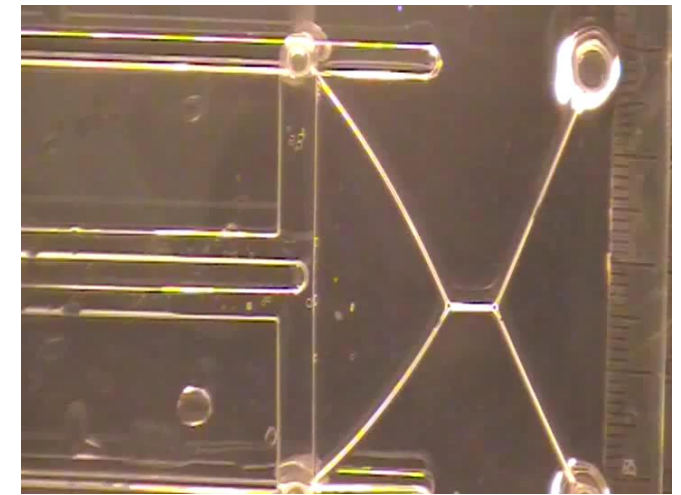
native β -lg
1.5 s



time for 90%
of final length

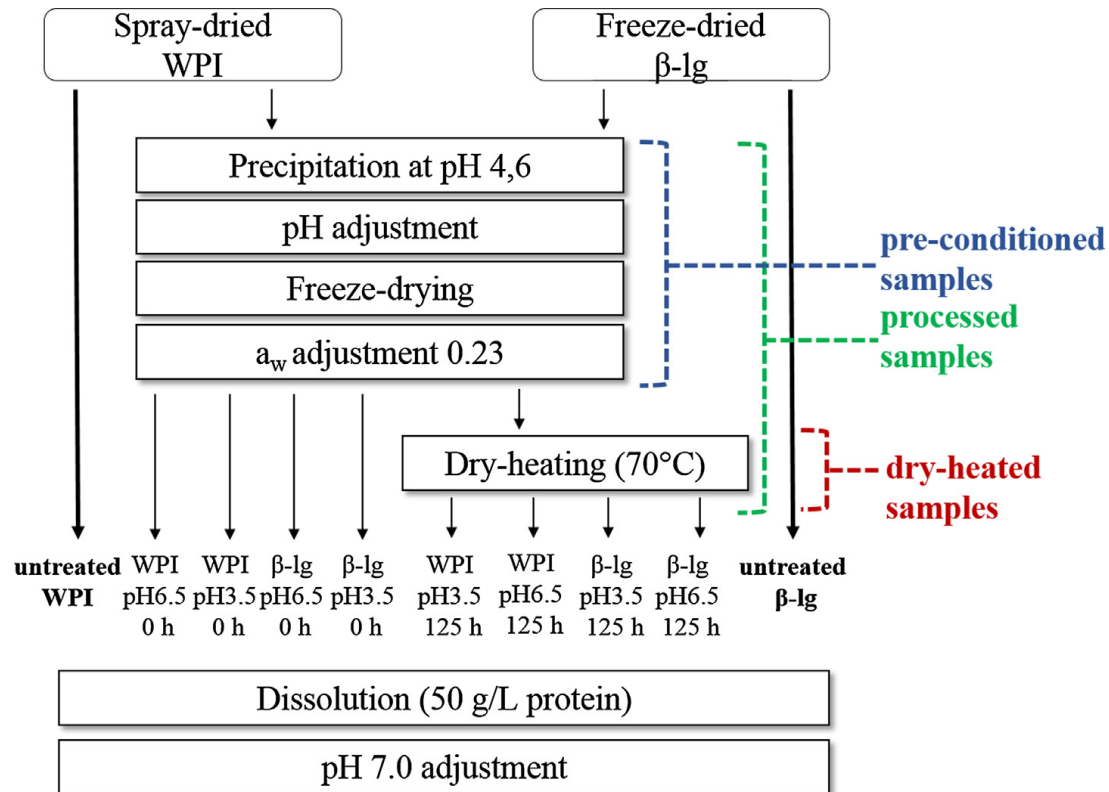


dry heated β -lg
4.6 s



Audebert et al., 2019 ([doi:10/cz9w](https://doi.org/10.1016/j.cj.2019.01.001))

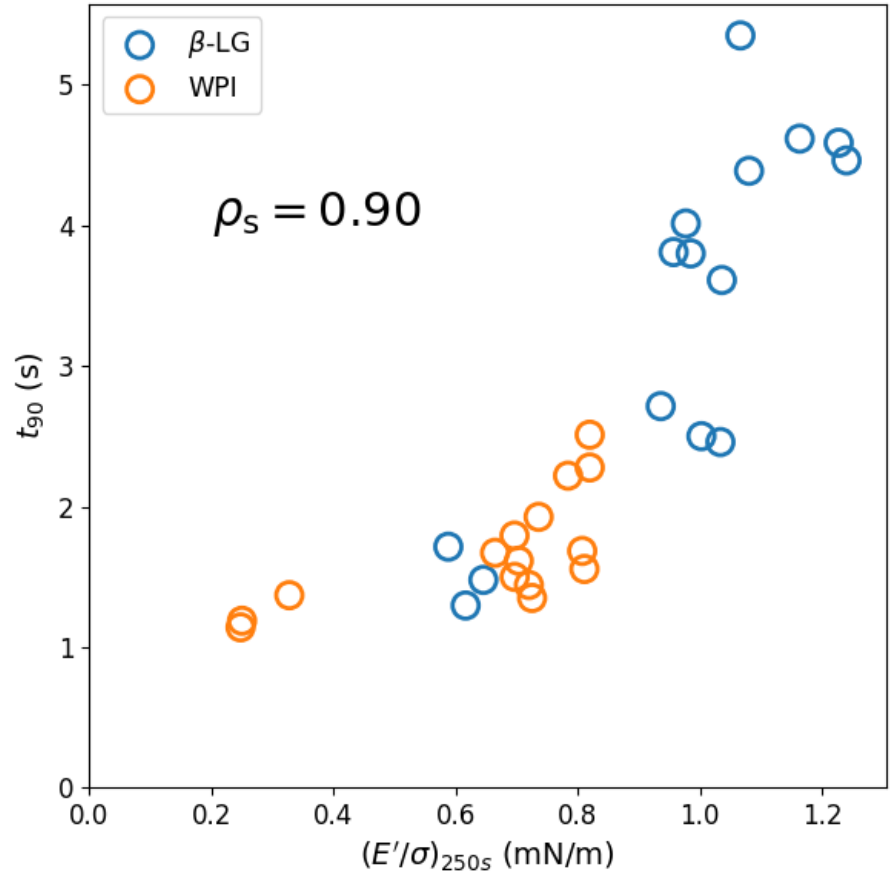
Protein modification



Audebert et al., 2019a ([doi:10/ctf8](https://doi.org/10.1016/j.foodchem.2019.125488)), 2019b ([doi:10/cz9w](https://doi.org/10.1016/j.foodchem.2019.125489))

Multiscale correlations

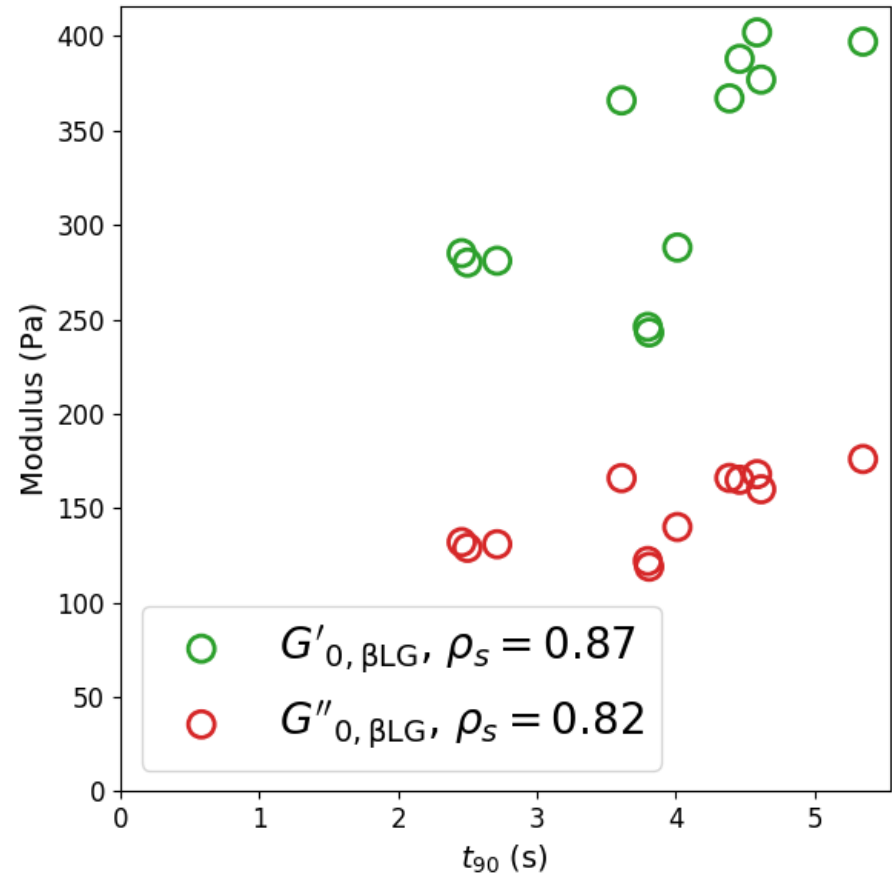
- interfacial rheology & T1



Audebert et al., 2019b ([doi:10/cz9w](https://doi.org/10.1016/j.cj.2019.03.009))

Multiscale correlations

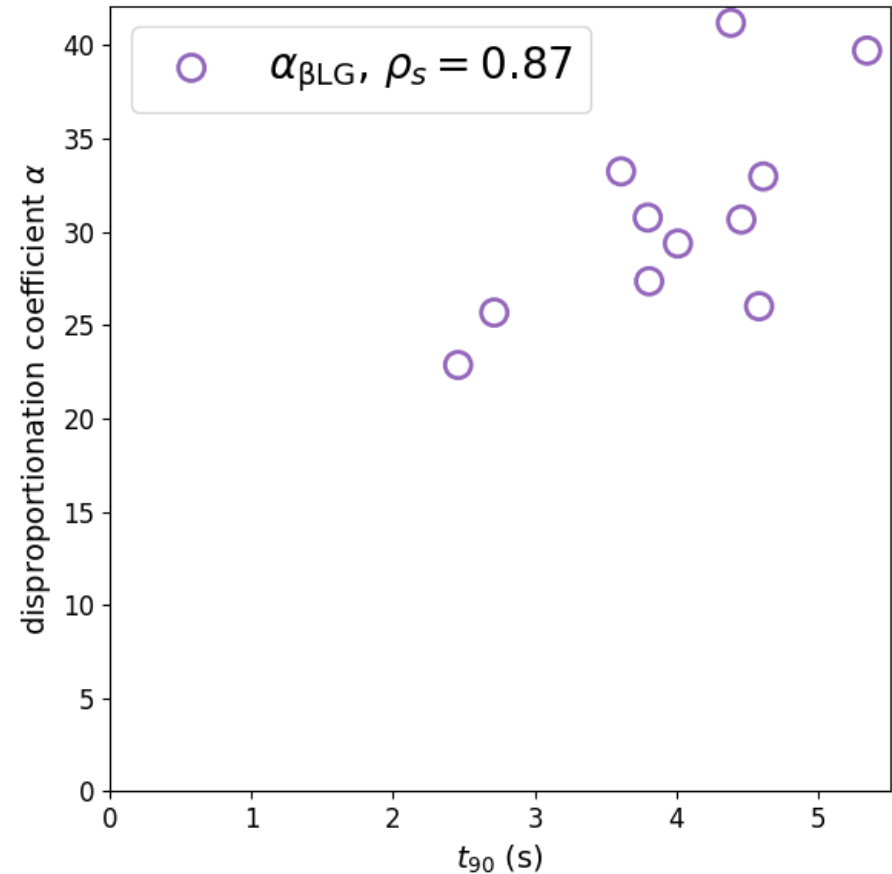
- interfacial rheology & T1
- T1 & foam rheology



Audebert et al., 2019b ([doi:10/cz9w](https://doi.org/10.1016/j.cj.2019.03.009))

Multiscale correlations

- interfacial rheology & T1
- T1 & foam rheology
- T1 & foam disproportionation



Audebert et al., 2019b ([doi:10/cz9w](https://doi.org/10.1016/j.cj.2019.03.009))

Conclusion

- film dynamics as an intermediate scale between interface and foam
- kinetics, early steps of interfacial film formation
- foam rheology as a functional criterion
- sensitivity to protein structure and stability
- food proteins: open questions in foam / colloid physics
- interdisciplinarity as a necessity

Zaccagnino et al., 2018 ([doi:10/cw2k](https://doi.org/10.1016/j.cw2k))

Acknowledgements

- *Sylvie Beaufigs (IPR)*
- *Arnaud Saint-Jalmes (IPR)*
- *Cécile Le Floch-Fouéré*
- *Alexia Audebert (PhD)*
- *Coralie Pasquier (PhD)*
- *Yann Desfougères (PhD)*
- *Antoine Bouchoux (LISBP)*
- *Bernard Cabane (CBI)*
- *Mikael Lund (Lund univ.)*
- *Simon J. Cox
(Aberystwyth univ.)*
- *Lay-Theng Lee (LLB)*

MERCI



**THANK YOU FOR
YOUR ATTENTION**

Key publications

- Audebert, A. et al. (2019) *J. Food Eng.* 242, 153–162
- Audebert, A. et al. (2019) *J. Colloid Interface Sci.* 542, 222–232
- Boire, A. et al. (2019) *Annu. Rev. Food Sci. Technol.* 10, 14.1–14.19
- Pasquier, C. et al. (2016) *Phys. Chem. Chem. Phys.*, 18, 28458–28465
- Desfougères, Y. et al. (2011) *Biomacromolecules*, 12, 156–166
- Desfougères, Y. et al. (2011) *Langmuir*, 27, 14947–14957
- Le Floch-Fouéré, C. et al. (2010) *Food Hydrocoll.*, 24, 275–284
- Le Floch-Fouéré, C. et al. (2009) *Food Hydrocoll.*, 23, 352–365