M1/M2 internship proposal – Soft Matter & Colloidal Physics

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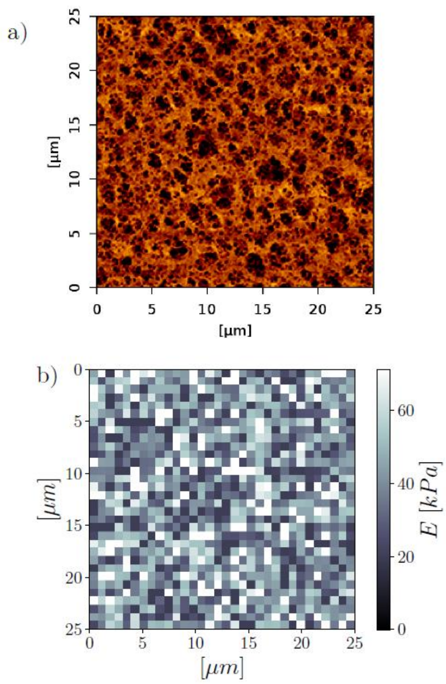
Feeling the Stress: Mapping Internal Stresses in Protein Gels

Context – **Colloidal gels** are crucial in biological networks, cell mechanics, food science, and building materials [1]. They form through the aggregation of sub-micron building blocks – polysaccharide coils, actin filaments, attractive globular proteins, or cement particles – which assemble into a percolated network (see Fig. a). This microstructure endows the material solid-like properties under small deformations and a rich nonlinear response, including strain-stiffening, micro-damage, and fracture [2,3].

Recent work has emphasized the key role of **frozen-in stresses** that develop during the sol-gel transition and later shape the nonlinear response of these gels [4]. However, these internal stresses have only been inferred indirectly at the macroscale, and **their spatial distribution at the microscale remains unknown**. As a result, the connection between these stress heterogeneities and the macroscopic failure scenario is still missing.



(a) Topography map and (b) map of the local elastic properties of an agar gel determined by AFM.

Internship objectives – The internship, part of the MICROFAT ANR project led by S. Manneville, aims to **bridge the gap between microscopic frozen-in stresses and the macroscopic nonlinear mechanical response of protein gels.** The student will:

- **Map the local mechanical properties** of protein-based colloidal gels [5] using atomic force microscopy and a **state-of-the-art nano-indenter** (PIUMA & CHIARO by Optics 11), providing spatially resolved measurements of local elastic moduli and residual stresses (Fig. b).
- Perform **local creep experiments under a confocal microscope** to probe how regions with different stress levels respond to deformation, stiffen, or fail.

Skills – We seek a motivated student with training in soft matter, physics, physical chemistry, or materials science. Skills in rheology, microscopy, or data analysis (Matlab/Python) would be an asset, but **training on all instruments will be provided**. Curiosity and motivation are the most important.

Practical information – **duration**: 4 to 6 months; **Level:** Master 1 or 2 (or 3A & 4A engineering schools); Send CV & short motivation letter to Thibaut.Divoux@ens-lyon.fr.

[1] Zaccarelli, *J. Phys.: Condens. Matter* **19**, 323101 (2007); [2] Leocmach, Perge, **Divoux** & S. Manneville, *Phys. Rev. Lett.* **113**, 038303 (2014) [link]; [3] B. Keshavarz, **T. Divoux**, S. Manneville & G.H. McKinley, *ACS Macro Letters* **6**, 663 (2017) [link]; [4] Pomella, Cipelletti & Ramos, *Phys. Rev. Lett.* **125**, 268006 (2020) ; [5] J. Bauland, G. Manna, **T. Divoux** & T. Gibaud, *Phys. Rev. Materials* **8**, L072601 (2024) [link]