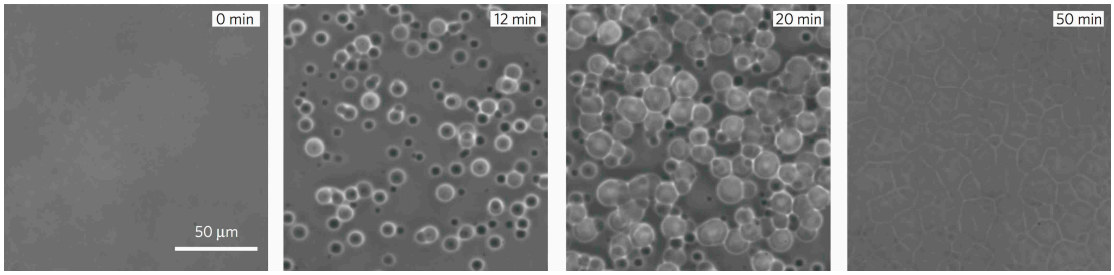
One substance, two liquid states? (BSc/MSc project)

Supervisors: Sander Woutersen and Daniel Bonn
Contact: s.woutersen@uva.nl

High-school physics books tell us that every substance can occur in three states: solid, liquid, gas. Can a substance have *two* liquid states? The obvious answer seems "no": you would expect that at any given temperature a substance has only one disordered thermodynamic state (as opposed to the well-known possibility of having more than one *ordered* state: think of the diamond and graphite phases of carbon). However, recent theory [1-3] and experiments [4] indicate that some substances may in fact have two liquid states. As a consequence, phase transitions between these two liquid states may occur (similar to the solid/liquid, liquid/gas phase transitions that we know from daily life), leading to strange thermodynamic properties such as liquid-liquid critical points, and the corresponding divergences of thermodynamic properties. It is suspected that water might be one of the substances having two liquid phases.

At present, the existence of liquid-liquid phase transitions is still very controversial [5], one of the main reasons being that the liquid-liquid phase transitions reported so far were observed mostly in mixtures (solutions) rather than in pure substances. In this project, you will investigate a pure substance for which we have strong evidence that it has two liquid phases. You will use a range of different experimental techniques to discover how the two liquid phases differ in structure and dynamics, both at the macroscopic and molecular level. Optionally, you can complement your experiments with computer simulations of the liquid-liquid transition.



Liquid-to-liquid phase transition in a water/glycerol mixture observed through a microscope. In a homogeneous liquid, droplets of a second liquid phase are formed, which eventually coalesce to form a second liquid phase. From reference [4].

[1] Poole, P. H., Sciortino, F., Essmann, U. & Stanley, H. E. Phase-Behavior of Metastable Water. *Nature* **360**, 324-328 (1992).
[2] Palmer, J. C. *et al.* Metastable liquid-liquid transition in a molecular model of water. *Nature* **510**, 385 (2014).
[3] Tanaka, H. Bond orientational order in liquids: Towards a unified description of water-like anomalies, liquid-liquid transition, glass transition, and crystallization. *Eur. Phys. J. E* **35**, 113 (2012).
[4] Murata, K.-I. & Tanaka, H. Liquid–liquid transition without macroscopic phase separation in a water–glycerol mixture. *Nature Materials* **11**, 436-442 (2012).
[5] Chandler, D. Metastability and no criticality. *Nature* **531**, E1-E2 (2016).