Particle response during the yielding transition of colloidal glasses

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Yielding is central to the relaxation, flow and fracture of a wide range of soft and molecular glasses, but its microscopic origin remains unclear. Here, we elucidate the yielding of a colloidal glass, silica particles 50nm in diameter, by using x-ray scattering (at DESY facility, Hamburg) to monitor the structure factor during the yielding process. We apply a recently introduced combination of vertical small-angle x-ray scattering and rheology [1] to the oscillatory shear measurements (see figure 1 left), and follow the structure factor evolution during the increasing strain amplitude. Surprisingly, we observe a sharp transition at critical strain $\gamma_0^\star$ in the orientational ordering of the nearest-neighbour structure upon yielding, in contrast to the smooth variation of the viscoelastic moduli (see figure 1 right). This transition is accompanied by a sudden change of intensity fluctuations towards Gaussian distributions. Interestingly the crossing point of the viscoelastic moduli occurs close to $\gamma_0^\star$, allowing us to associate the sharp structural transition with the rheological yielding of the material. Even during the reverse transition, i.e. from large to small strain amplitude the structural transition at $\gamma_0^\star$ happens close to the intersection of the moduli, with almost no hysteresis. We thus identify yielding as a new, dynamically induced transition of the glass in response to the applied shear [2].
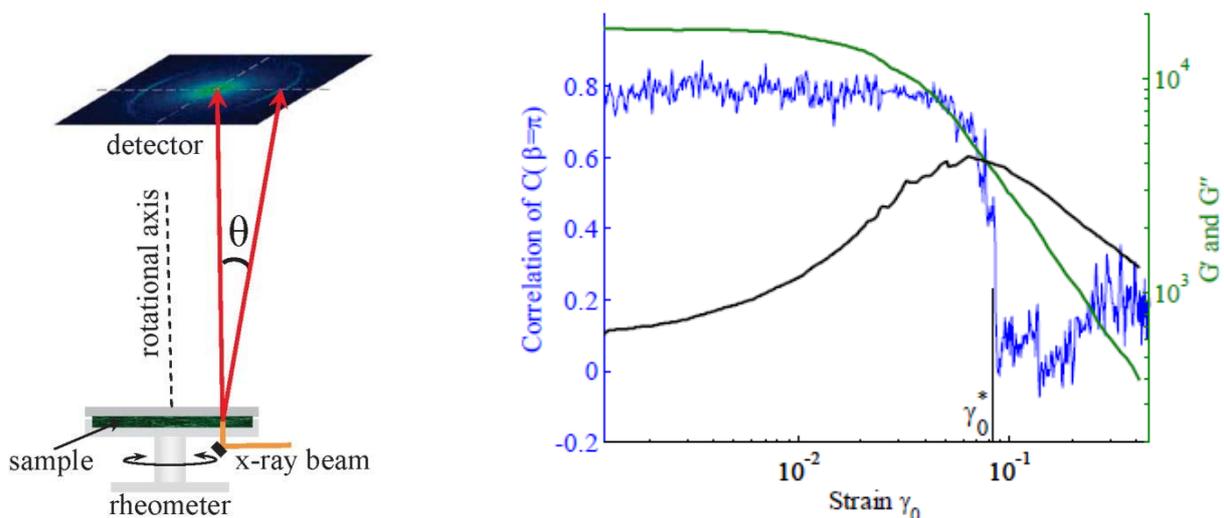
Figure 1. Left: Schematic of the experimental setup showing the x-ray beam and detector with respect to the rheometer and the layer of sheared suspension. The rheometer is stress controlled and we use plate-plate geometry. The x-ray beam passes through the suspension at 0.78 times the disc radius; the beam diameter is smaller than 0.1 mm, much smaller than the disc radius of 18mm. Right: Nearest-neighbor orientational order parameter $C(\beta = \pi, \gamma_0)$ as a function of strain amplitude γ_0 (left axis, blue curve). Also indicated are the elastic and viscous moduli, G' and G" (right axis, green and black curves).

[1]   D. V. Denisov, M. T. Dang, B. Struth, G. H. Wegdam, P. Schall, "Resolving structural modifications of colloidal glasses by combining x-ray scattering and rheology", Nature Scientific Reports 3, 1631 (2013)

[2]   D. V. Denisov, M. T. Dang, B. Struth, G. H. Wegdam, P. Schall, "Particle response during the yielding transition of colloidal glasses", arXiv:1401.2106 [cond-mat.soft]