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Editorial: Probing out-of-equilibrium soft matter

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Editorial on the Research Topic
Probing out-of-equilibrium soft matter

This Research Topic originates from the symposium *Probing Out-of-Equilibrium Soft Matter* that was held on October 22–23, 2021 at the University of Fribourg (Switzerland) to celebrate and honor the career of Véronique Trappe (https://orcid.org/0000-0002-0301-258X). The symposium assembled leading scientists in the rapidly growing field of non-equilibrium soft matter physics, a field to which V. Trappe has made key contributions that have changed the view of many [1–6]. While the equilibrium behaviour of soft matter is amply studied and understood, novel tools are needed to capture the complexity of out-of-equilibrium soft materials. A particular challenge is getting access to and understanding the fast processes occurring at the nano- and micro-scale of the elementary constituents, while simultaneously capturing the slower evolution of bulk properties in non-equilibrium conditions. To take on this task, new theoretical, numerical and experimental methodologies need to be developed that enable the investigation of the structure, dynamics, thermodynamics, and rheology of out-of-equilibrium soft matter. Adopting a comprehensive view that covers fundamental topics as well as research focusing on processes and issues faced in applications, this Research Topic aims to showcase some of the latest advancements and innovations in the field.

Living and active materials are intrinsically non-equilibrium systems due to metabolic activity and/or energy consumption. Using newly developed fabrication and image processing tools, Chang et al. probe the effect of surface curvature on the proliferation of Madin-Darby Canine Kidney (MDCK) epithelial cells. They show that proliferation is insensitive to changes in curvature, and that the main mechanism of cell proliferation control is contact inhibition. Sheung et al. use a combination of light sheet microscopy, particle tracking, and differential dynamic microscopy to elucidate anomalous and advective transport in actomyosin-microtubule biomimetic composites. A complex interplay between increasing activity and confinement as the actomyosin fraction increases governs the transport properties of these active cytoskeletal systems.

Three studies address shear-driven patterning in soft materials. Applying shear flow during the temperature-induced gelation of a colloid-polymer mixture which contains thermosensitive microgel particles, Rel et al. show that they can tune the morphology of mesoscopic colloidal clusters. Gels comprised of fibrous, elongated colloid-dense clusters, log-like flocs that are aligned along the vorticity direction or isotropic clusters can be produced by controlling the shear. Villa et al. adapt a previously designed shear cell [7] to perform stress-controlled rheo-microscopy experiments on commercial microscopes. This flexible rheo-microscopy setup, compatible with different imaging methods, allows to perform quantitative rheology by assessing the microscopic dynamics with particle tracking and differential dynamic microscopy analysis. Lastly, Miller et al. introduce a novel approach to assess dynamic ordering in sheared dense suspensions using a combined rheometer and laser scanning confocal microscope. The spatiotemporal dynamics obtained with high spatial and temporal resolution reveals distinct regimes of ordering depending on the particle concentration and the applied stress, which reflect shear-thickening and transiently shear-jammed states.

Colloidal suspensions are also the focus of Carpineti et al., who study the transient patterns that emerge during Rayleigh-Bénard convection with thermophilic particles. The gravitationally destabilizing temperature gradient induces rotating patterns in the form of traveling waves that eventually disappear as the stabilizing effect of thermophoresis returns the system to a conductive state. Probing the crystallization kinetics of charged temperature-sensitive microgels in deionized conditions, Bocanegra-Flores et al. discover that due to their microgels' low polydispersity and electrostatic charge a liquid-crystal transition occurs for volume fractions of the order of 0.01–0.05, a factor of ten lower than in neutral microgels.

Soft Matter research is increasingly impacted by current developments in Machine Learning (ML) techniques. Methods including computer vision, feature engineering, and classification tasks have been applied to characterize colloidal systems. In particular, ML methods have proven useful to identify correlations in non-equilibrium systems such as glasses. Oyama et al. discuss how deep neural networks can predict the characteristic local meso-structures of glasses solely from instantaneous particle configurations, without any information about the particle dynamics. Finally, the nature of the non-equilibrium states also depends on how rapidly a material is quenched to a specific condition. Rouzaire and Levis discuss the dynamics of the short range noisy Kuramoto model, where spins are able to rotate with an intrinsic frequency taken from a quenched Gaussian distribution. By connecting synchronisation with the so-called topological Berezenskii-Kosterlitz-Thouless phase transition, the authors investigate the dynamics of vortices and other topological defects, shedding light on their long-time super-diffusive behaviour.

The articles of this Research Topic are representative, while non-exhaustive, of a variety of out-of-equilibrium phenomena in Soft Matter that are rapidly emerging among the most fascinating topics in modern multidisciplinary science. Symposia and workshops such as the one that inspired this Research Topic will continue to play an important role in promoting and deepening interactions between researchers with diverse backgrounds. The ability to discuss openly and in depth, so distinctive of Véronique Trappe's way of conducting research, will be key to continue progress in the field.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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References

1. Trappe V, Prasad V, Cipelletti L, Segre P, Weitz DA. Jamming phase diagram for attractive particles. *Nature* (2001) 411:772–5. doi:10.1038/35081021

2. Cipelletti L, Bissig H, Trappe V, Ballesta P, Mazoyer S. Time-resolved correlation: A new tool for studying temporally heterogeneous dynamics. *J Condens Matter Phys* (2003) 15:S257–62. doi:10.1088/0953-8984/15/1/334

3. Trappe V, Sandkühler P. Colloidal gels—Low-density disordered solid-like states. *Curr Opin Colloid Interf Sci.* (2004) 8:494–500. doi:10.1016/j.cocis.2004.01.002

4. Cerbino R, Trappe V. Differential dynamic microscopy: Probing wave vector dependent dynamics with a microscope. *Phys Rev Lett* (2008) 100:188102. doi:10.1103/physrevlett.100.188102

5. Bischofberger I, Calzolari DC, De Los Rios P, Jelezarov I, Trappe V. Hydrophobic hydration of poly-N-isopropyl acrylamide: A matter of the mean energetic state of water. *Sci Rep* (2014) 4:4377. doi:10.1038/srep04377

6. Caggioni M, Trappe V, Spicer PT. Variations of the herschel–bulkley exponent reflecting contributions of the viscous continuous phase to the shear rate-dependent stress of soft glassy materials. *J Rheol* (2020) 64:413–22. doi:10.1122/1.5120633

7. Aime S, Ramos L, Fromental JM, Prevot G, Jelinek R, Cipelletti L. A stress-controlled shear cell for small-angle light scattering and microscopy. *Rev Sci Instrum* (2016) 87:123907. doi:10.1063/1.4972253