

## **New statistical physics in living matter: non equilibrium states under adaptive control**

**Abstract:** Life is an active, emergent process far from equilibrium and involving spatiotemporal organization across scales. Recent advances in the non-equilibrium statistical mechanics of active matter, along with such new experimental techniques as super-resolution microscopy and computational methods as machine learning, have opened new approaches for research on living systems. The programme focused on identifying mathematical techniques from non-equilibrium statistical mechanics that can be applied to biology at cellular and tissue scales, as well as new mathematical problems inspired by biology at this scale. This involved new types of non-equilibrium phase transitions in epithelial sheets and tissues, the coupled mechanochemistry of motor proteins and filamentous assemblies, membraneless cellular organelles formed by phase separation, and self-assembly processes such as those found in the replication cycle of viruses. These themes brought together mathematicians and physicists specialising in theoretical and experimental soft matter and biophysicists to support this growing field and made it possible to forge new collaborations across disciplines.

**Main:** Biological systems constantly dissipate energy, do work, and can perform complex motions, i.e., they operate far from thermal equilibrium. The frameworks of equilibrium thermodynamics and statistical mechanics that are so successful for soft materials (of which biological systems are made) is therefore often not applicable to living systems. The New Statistical Physics of Living Systems (SPL) program aimed at bringing together different scientific communities together to address the challenge of developing new theoretical frameworks. This programme included communities working on (i) non-equilibrium statistical mechanics and simplified models, (ii) theoretical soft and active biological matter, (iii) experimental biophysics, and (iv) machine learning.

SPL focused on biologically diverse phenomena occurring at different spatial and temporal scales in four workshops. The first broad workshop aimed at bridging non-equilibrium statistical physics and biophysics (41 speakers and 133 attendees). This was followed by a second workshop on active matter from single cells to cell layers, tissues and development at different scales, from cytoskeletal filaments to tissues and organoids (40 speakers and 102 attendees). It included a special session in memory of Prof. Alex J. Levine, one of the instigators of the program who passed away before its start. The third workshop focused on cellular organelles that are formed and maintained via phase separation processes, followed by a week-long mini workshop on Gene regulation and cell fate decisions that brought in experimental biologists to interact with the program participants. SPL held a fourth satellite workshop at Edinburgh University, focusing on the non-equilibrium physics of biological self-assembly (39 invited speakers, 70 attendees). The program was complemented by an Open for Business event focussing on the mechanics of cell walls across bacteria, plants, and fungi, as well as antimicrobial resistance. There was an EDI session discussing issues facing researchers from marginalized communities. In addition, we had a special one-day workshop commemorating the life and science of Prof. T. C. B. McLeish, FRS, an eminent member of the UK Biological Physics community

The programme provided a welcome boost to research efforts, new collaborations, and mentoring of junior researchers in the field. The majority of participants initiated new collaborations, began research in new directions, and learned of new applications.

Immediate achievements include new results on fluctuations of non-equilibrium systems, active matter, wound healing dynamics, filamentous assemblies, and fluctuating membranes and vesicles that are either motivated or testable by experiments. Plans are currently in place for follow-up activities in the form of short workshops at international venues across Europe, Asia, Africa, and the Americas to build a strong community working in this area.