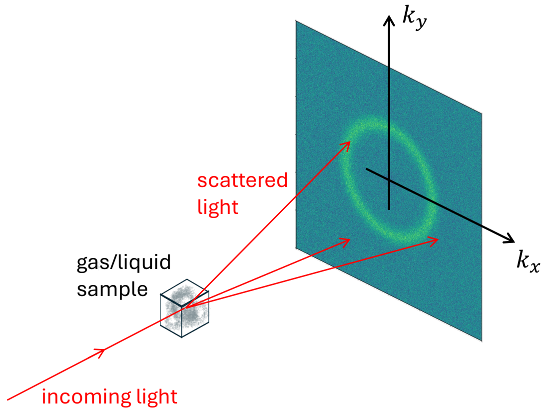
School of Mathematics and Statistics
Faculty of Science, Technology, Engineering and Mathematics

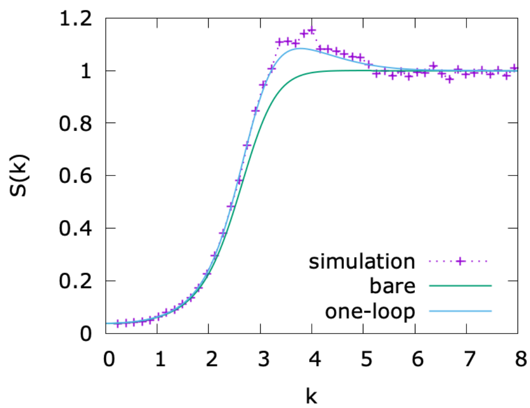
2026 PhD Projects

Project title	Feynman diagram approach to the structure and dynamics of nonequilibrium liquids
Principal supervisor	Elsen Tjhung
Second supervisor	Marc Pradas
Discipline	Applied mathematics / theoretical physics
Research area/keywords	Statistical physics, stochastic processes, fluid dynamics
Suitable for	Full time applicants, part time applicants

Project background and description

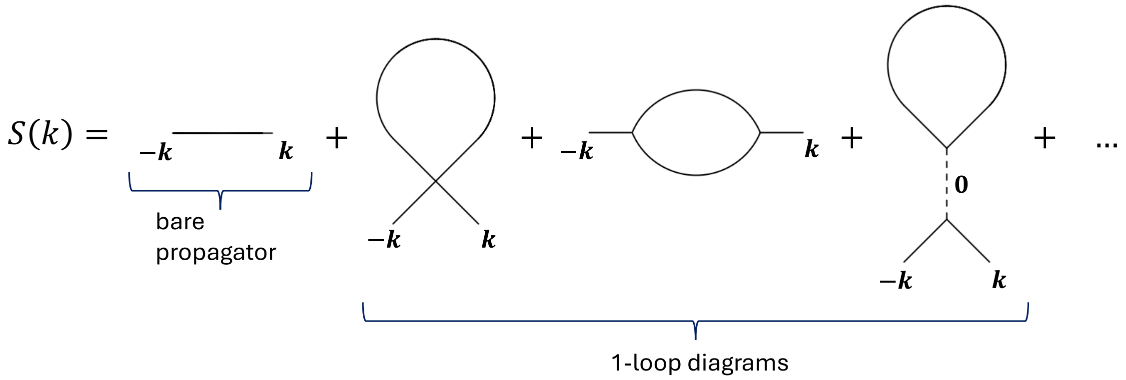
When monochromatic light is shone onto a material, it is scattered into different directions on a two-dimensional plane (k_x, k_y). The intensity pattern of this scattered light defines the structure factor, $S(\mathbf{k})$, which encodes information about the spatial correlations between atoms or molecules within the material. In a solid, atoms are arranged in a regular, periodic lattice. As a result, $S(\mathbf{k})$ exhibits sharp Bragg peaks arranged with the symmetry of the underlying crystal (for example, sixfold symmetry in hexagonal lattices). In contrast, a liquid lacks long-range order, and the positions of atoms fluctuate more randomly. Consequently, $S(\mathbf{k}) = S(|\mathbf{k}|)$ becomes isotropic, typically forming concentric rings rather than discrete peaks.





In this PhD project, we will develop a field-theoretic perturbation framework based on Feynman diagrams to study the structure and dynamics of equilibrium and nonequilibrium fluids.

For equilibrium fluids, we will first construct a systematic diagrammatic expansion for the structure factor, starting from the Gaussian approximation and including higher-order loop corrections (e.g. the one-loop and two-loop levels). These corrections capture the effects of interactions and correlations beyond mean-field theory.



Once the method is established, we will extend it to nonequilibrium fluids, such as driven, sheared, or active (living) fluids composed of self-propelled particles or microswimmers. This generalisation will allow us to explore how external driving or internal activity modifies the statistical correlations and dynamic relaxation of such systems—an open question at the forefront of nonequilibrium statistical physics.

Background reading/references

- R. P. Feynman, QED - The Strange Theory of Light and Matter (Penguin Press Science, 1990)
- M. Kardar, Statistical Physics of Fields (Cambridge University Press, 2007)
- U. Tauber, Critical Dynamics (Cambridge University Press, 2014)
- D. S. Dean, Langevin equation for the density of a system of interacting Langevin processes, *J. Phys. A: Math. Gen.* **29** L613 (1996)
- B. Kim and K. Kawasaki, A fluctuation-dissipation relationship-preserving field theory for interacting Brownian particles: one-loop theory and mode coupling theory, *J. Stat. Mech.* P02004 (2008)