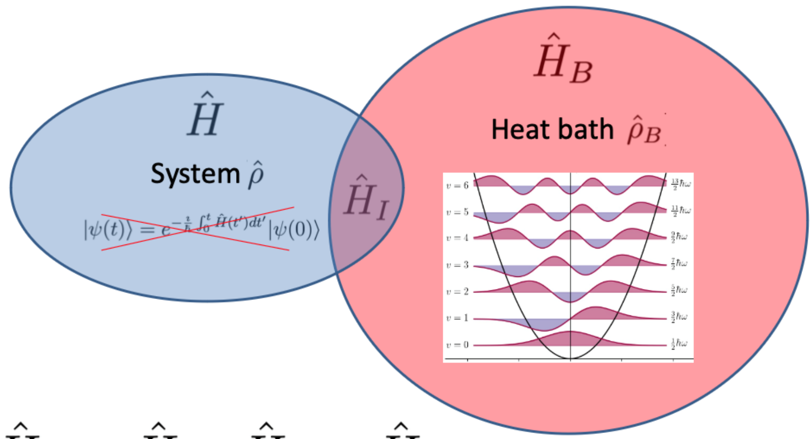
MULTISCALE STATISTICAL AND QUANTUM PHYSICS (MSP) Group - For more information about the group, please visit https://qtf.fi/research

The MSP group is part of the Quantum Technology Finland Center of Excellence, and we are looking for motivated and talented students to join us for summer research in 2024. We have multiple projects for BSc and MSc students. We expect the students to have some understanding of quantum physics, statistical mechanics and thermodynamics. Knowledge of one or more numerical tools (like Mathematica, MATLAB/Python) is an advantage, but not necessary. We can offer several types of projects in different subfields of physics and applied mathematics depending on the background, experience and interest of the student.

Thermodynamics of Open Quantum Systems (supervisor Dr. Jishad Kumar)

Recent technological advancements in quantum physics can easily realize a nano-electromechanical system, a quantum dot (or a quantum well), a nano heat engine or a refrigerator in a laboratory. When the system size is considerably small (such as in a nano or mesoscopic system), isolating them from their surrounding is impossible. This means that small systems (or parts of them) are significantly coupled to their environment. The canonical state of a classical open system remains a Gibbs' state since the coupling energy is easily neglected compared to the reasonably large thermal energy of the system. However, at very low temperatures, particularly when quantum effects dominate this coupling energy cannot be discarded. This can raise questions about the validity of known thermodynamic laws and how to define thermodynamic quantities in such situations.

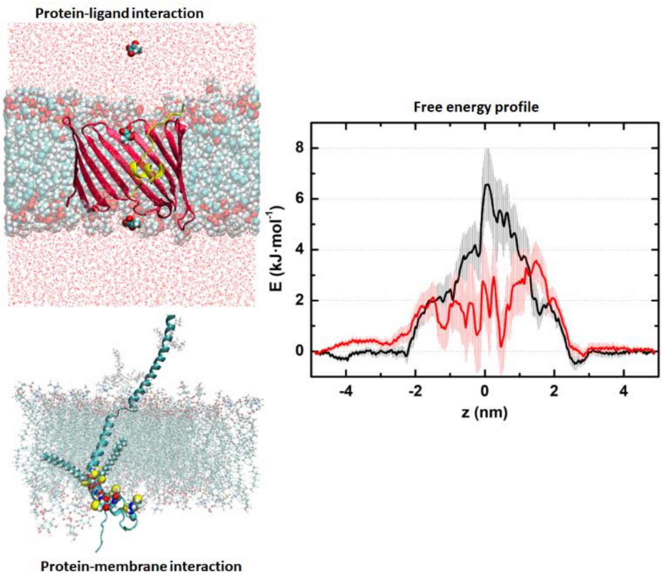


$$\hat{H}_T = \hat{H} + \hat{H}_B + \hat{H}_I$$

You will be working on 1) comparison of various approaches to open quantum systems; or 2) quantum heat engine cycles (Otto and Stirling) of certain systems (working substances) with non-Markovian heat/cold reservoir. In addition to the above-mentioned topics, other topics related to quantum heat transport and low-temperature behavior of quantum dot structures at high magnetic field are offered. You need not be an expert in any of the topics, but a scientific curiosity is required. You need to have the patience to sit and do some analytical calculations.

Computational Studies on Biological Systems (supervisor Dr. Maryam Ghasemitarei)

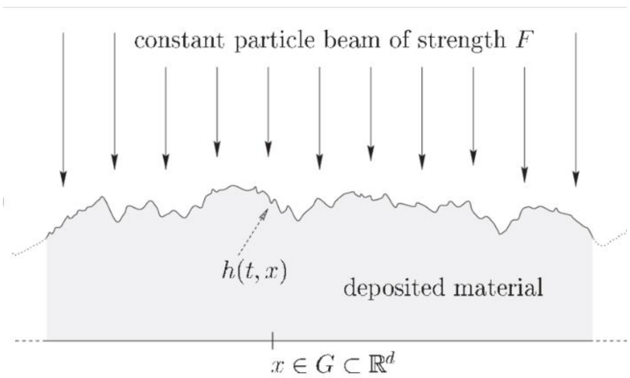
In recent years, computer simulations have played an important role in making connection between theory and experiment. Among the different types of computer simulations, molecular dynamics (MD) is a very useful method to investigate the influence of interactions in atomistic systems. The basis of MD simulations is the integration of the equations of motion of the particles. Evolution of biological systems containing proteins, lipids, glycans and nucleotides is very complex, but it can be studied by MD simulations. The various MD techniques such as steered MD, targeted MD, accelerated MD, umbrella sampling and free energy perturbation can be used to find the free energy of biological systems.



In this research project, you will prepare atomistic models of mixtures of biological components including proteins, membranes, etc., and study their time evolution and interactions with active ligands using various MD simulation techniques. In addition, you may employ quantum-mechanical Density Functional Theory (DFT) calculations to obtain accurate parameters required for the simulations.

Efficient Numerical Solvers for Stochastic Nonlinear PDEs (T.A-N., N.N.)

Stochastic partial differential equations (SPDEs) emerge in many models of physical systems where there is an external driving force and some inherent stochasticity (randomness) in the underlying physical processes. One of the simplest examples is surface growth, where particles are randomly deposited on a substrate and aggregate to form a moving interface $h(x,t)$ which may become increasingly rough (irregular) in time.



Perhaps the most famous SPDE to describe the dynamics of the interface in these types of systems is the Kardar-Parisi-Zhang (KPZ) or Stochastic Burgers equation, which is also nonlinear in the height field $h(x,t)$. Such equations have no known analytic solutions and must be treated numerically. In this project you will become familiar with the properties of SPDEs and compare different numerical methods for solving them in a computer. To this end, some programming and data analysis skills are required.