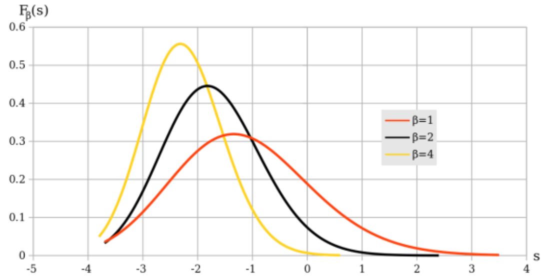
TIFX04-22-23
Universal correlations in non-interacting Fermi gases



Bakgrund: Assume that you know the position of every particle in a liquid and that you can predict the trajectory for each of these particles over time. What have you then learned about a glass of water? Of course, the answer is 'nothing' — knowing the trajectory of a single particle in such a complex system is not useful. What we are after is a statistical description, which tells us, for example, which fraction of the particles have certain velocities or the probability to detect particles in a certain volume. Such a statistical description is very important: As a case in point, the Nobel Prize in Physics this year was awarded to Manabe, Hasselmann and Parisi for the statistical modelling of the climate as well as systems called 'spin glasses'.

In quantum physics, the particle type (boson or fermion) is important for the statistical description: You are probably familiar with the difference between Maxwell-Boltzmann (for classical particles), Fermi-Dirac (for fermions), and Bose-Einstein distributions (for bosons). But how important exactly has only been realised very recently: Even non-interacting quantum particles have a description that was previously only seen in complicated systems like atomic nuclei (which have strong interactions between their constituents) or models that describe the spread of forest fires and avalanches. This is both surprising and exciting, because these quantum systems can be created in experiments with ultracold gases and nanostructures.

Problembeskrivning: In this project, you will apply techniques from your quantum mechanics course to describe non-interacting Fermi quantum gases. The aim is to develop a statistical description for the position of the particles and make predictions that could be tested in experiments.

Arbetssätt: This is a project in theoretical physics. You will analyse a theoretical model, and use it to derive a number of fundamental identities and perform a few (either analytical or numerical) calculations. Some knowledge of computer algebra systems (such as Mathematica or Matlab) is helpful, but by no means necessary.

Gruppstorlek: This project is suitable for one or two groups of 3-5 students.

Målgrupp: F, GU-fysik, IT, or equivalent — everyone with an interest in quantum mechanics and/or statistical physics

Litteraturtips:

- This year's Nobel Prize in Physics was awarded for ground-breaking contributions to the statistical description of complex systems. A very accessibly introduction is
  https://www.nobelprize.org/uploads/2021/10/sciback_fy_en_21.pdf
- A general introduction to quantum gases is: J. Thomas and M. Gehm, *"Optically Trapped Fermi Gases"*, American Scientist **92**, p. 238 (2004)
  https://www.physics.ncsu.edu/jet/publications/pdf/AmericanSci04Thomas.pdf
- A review paper with (rather advanced) theory: D. Dean, P. Le Doussal, S. Majumdar, G. Schehr, *"Non-interacting fermions at finite temperature in a d-dimensional trap: universal correlations"*, Phys. Rev. A **94**, 063622 (2016)
  https://arxiv.org/abs/1609.04366

Handledare: Johannes Hofmann, johannes.hofmann@physics.gu.se