Linear response and sum rules of ultracold atomic gases

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Linear response theory provides a general theoretical framework to investigate collective modes of Bose-Einstein condensates and superfluids. A sum-rule approach is also very useful for this purpose because the ground state for a dilute-gas Bose-Einstein condensate can be obtained very accurately. Superfluidity manifests itself as a response of the system to its moving container. A statistical mechanical theory to address such problems and some basic properties of superfluidity are discussed. All of these properties are investigated by using time-ordered response functions. We will also discuss out-of-time-ordered correlations functions which have attracted considerable interest in recent years due to their relevance to nonlinear response and quantum chaos.

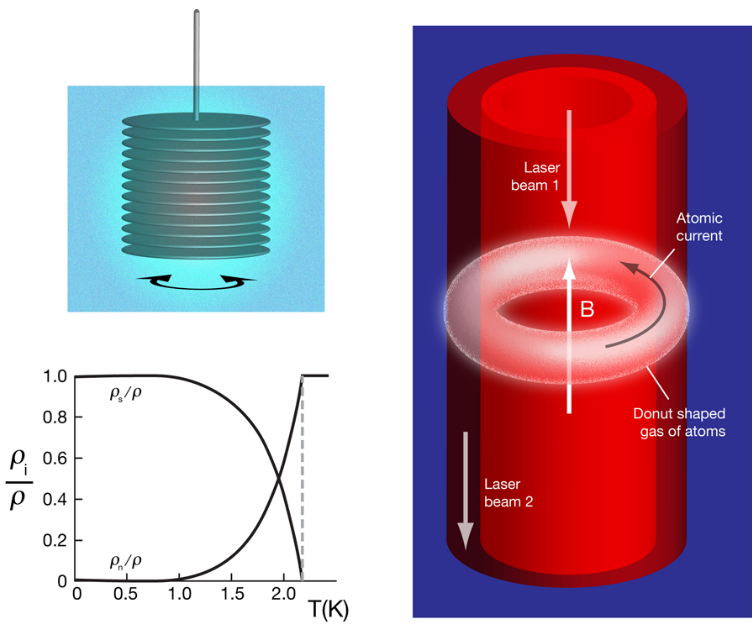

Figure 1: (Left) In 1946, Andronikashvili carried out a classic experiment on superfluid liquid helium by measuring the period and damping rate of a torsional oscillator consisting of a stack of closely spaced cylindrical plates hanging by an elastic thread and immersed in the liquid helium. The normal component of the fluid was dragged along by the rotating disk surfaces, while the superfluid took no part in the rotational motion, which allowed measurement of the fraction of the superfluid component as a function of temperature (bottom panel). (Right) Cooper and Hadzibabic [1] propose an optical method to measure the superfluid fraction in ultracold atomic gases. The pair of copropagating laser beams with different orbital angular momenta create an azimuthal vector potential that imparts angular momentum to the normal component but leaves the superfluid one at rest. Spectroscopic analysis permits measurement of the induced angular momentum and hence the amount of normal versus superfluid gas. (Figure taken from [2].)

[1] N.R. Cooper and Z. Hadzibabic, *Measuring the Superfluid Fraction of an Ultracold Atomic Gas*, Phys. Rev. Lett. **104**, 030401 (2010)

[2] I. Carusotto, *Viewpoint: Sorting superfluidity from Bose-Einstein condensation in atomic gases*, Physics **3**, 5 (2010)