Creating and Detecting Weyl Bosons with Ultracold Fermi Atoms

Carlos A. R. Sá de Melo

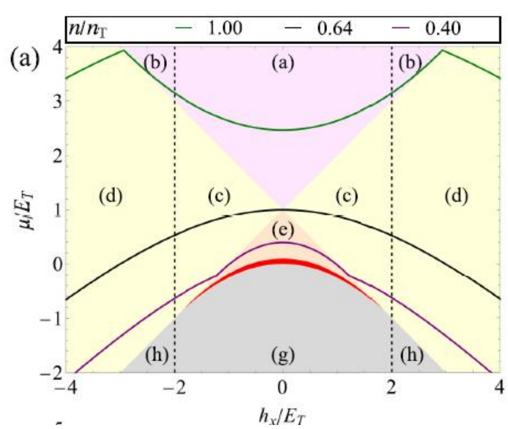
School of Physics, Georgia Institute of Technology

Inspired by investigations of Dirac, Majorana and Weyl fermions in the context of particle, condensed matter and atomic physics, we propose theoretical and experimental platforms to create and detect massless helical boson modes that we call Weyl bosons, the bosonic cousins of Weyl fermions [1]. We show that these exotic excitations arise naturally in one-dimensional interacting Fermi gases, when spin-orbit coupling and Rabi fields are present, through the mixing charge and spin degrees of freedom [2]. We obtain the phase diagram of chemical potential versus Rabi fields for given spin-orbit coupling and interactions, showing regions where zero, one or two types of Weyl bosons exist. We find that, when two types of Weyl bosons emerge, they must propagate with different velocities. Furthermore, we show that the disappearance of any Weyl boson species is described by a topological quantum phase transition of the Lifshitz type, where the velocity of the disappearing Weyl boson vanishes, and the velocity of the surviving Weyl boson develops a cusp at the transition boundary. Lastly, to detect the existence of Weyl bosons, we propose measurements of the dynamic structure factor tensor (charge-charge, charge-spin and spin-spin), where the energy dispersions, spectral weights and helicities of the emergent Weyl bosons may be experimentally extracted in ultracold Fermi systems such as ^{6}Li, ^{40}K, ^{173}Yb and ^{87}Sr.

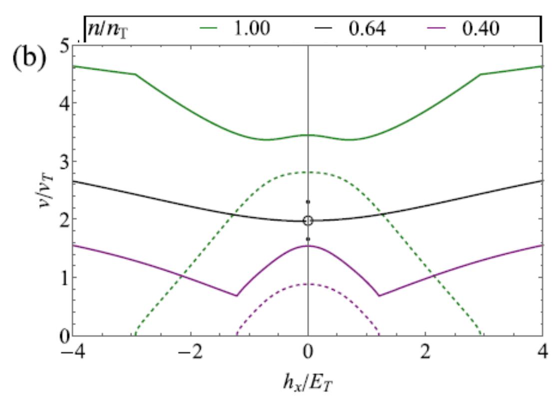
[1] "Creating and detecting Weyl bosons with ultracold Fermions", Xiaoyong Zhang and C. A. R. Sá de Melo, Phys. Rev. A **113**, L011303 (2026); https://doi.org/10.1103/4dj8-6wbb

[2] "Effects of spin-orbit coupling and Rabi fields in Tomonaga-Luttinger liquids: current status and open questions", Xiaoyong Zhang and C. A. R. Sá de Melo, Comptes Rendus Physique (French Academy of Sciences), Vol. 26, p. 483-514 (2025); https://doi.org/10.5802/crphys.254

Phase Diagram



Velocities of Weyl Modes



Speaker Profile

Prof. Carlos A. R. Sá de Melo earned a PhD in theoretical physics at Stanford University (1991), specializing in quantum many-body physics, under the supervision of Prof. Sebastian Doniach (Bardeen Prize 2018), and was a postdoctoral fellow at the Science and Technology Center for Superconductivity in Illinois, mentored by Dr. Alexei Abrikosov (Nobel Prize 2003, deceased). After that he moved to the Georgia Institute of the Technology, where he is a professor of physics today.

Prof. Sá de Melo is best known for his theoretical contributions to the evolution from Bardeen-Cooper-Schrieffer (BCS) to Bose-Einstein condensation (BEC) superfluidity and superconductivity in single- and two-band systems during the 1990's and 2000's, a phenomenon that has been explored experimentally since the mid-2000's.

For his work on ultracold Fermi atoms, superfluids and superconductors, he was awarded a two-year Visiting Fellow position at the Joint Quantum Institute (UMD-NIST) from 2006-2008, was elected Fellow of the American Physical Society in 2012, was granted a Simons Fellowship in 2017 for an extended visit to the Galileo Galilei Institute of Theoretical Physics (Florence, Italy), was presented the Fibonacci Prize in 2018 at the Quantum Complex Matter conference (Frascati, Italy), was elected Fellow of the American Association for the Advancement of Science in 2021, and was honored with a Mercator Fellowship by the German Research Foundation in 2024.

His research on the crossover and quantum phase transitions from the BCS to the BEC regime in superfluids and superconductors has influenced experimental and theoretical work not only in atomic, but also in nuclear and condensed matter physics.