Cold Atoms

This area of research focuses on the study of equilibrium phase diagrams and nonequilibrium dynamics of cold atoms. These systems offer a large degree of tunability and are essentially disorder-free [1]. One can thus address experimentally a number of fundamental questions without having to face the typical complications of solid-state environments. The work reported below has been done in collaboration with several people, including K. Capelle (IFSC, Brazil), M. Cazalilla (CSIC-UPV/EHU, Donostia-San Sebastian, Spain), C. Kollath (Ecole Polytechnique, France), X. Gao (Zhejiang Normal University, China), and G. Vignale (University of Missouri-Columbia, USA).

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Equilibrium phase diagrams

In Ref. [2] we have studied by means of the density-matrix renormalization-group (DMRG) technique a two-component atomic Fermi gas with *attractive* interactions inside a 1D optical lattice. We have demonstrated how this system exhibits phases characterized by atomic-density waves (ADWs), and we have shown how the existence of ADWs can be detected by measuring the light-scattering diffraction pattern. In Ref. [3] we have studied a similar system, but in the presence of a finite spin polarization. By means of the DMRG we have computed the pairing correlations in the whole range from weak to strong coupling. We have demonstrated that pairing correlations exhibit quasi-long range order and oscillations at the wave number expected from the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) theory and we have shown that charge and spin degrees of freedom are coupled already for small spin polarization.

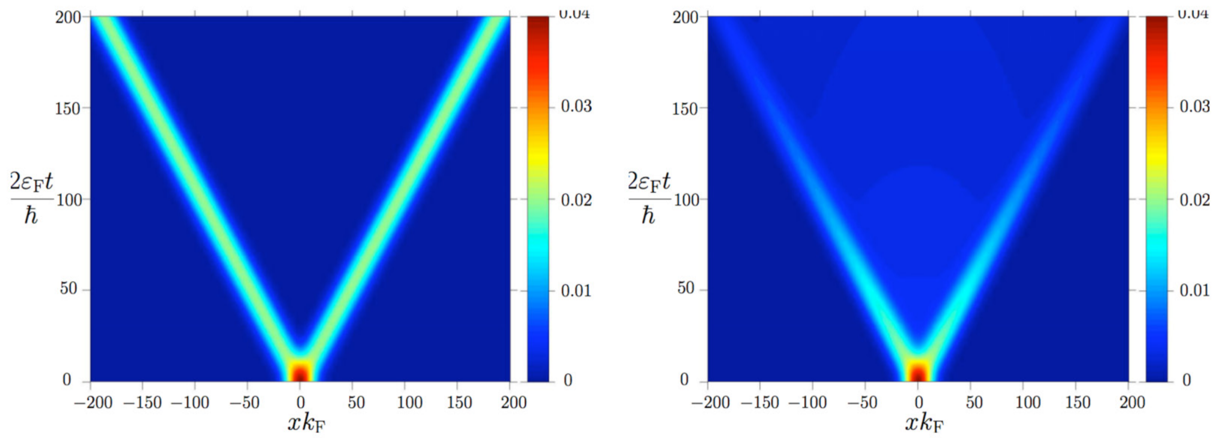


Fig. 1
(Left panel) Space-time evolution of a spin packet in the ballistic limit (no spin-drag). The left and right components of the packet propagate at the Fermi velocity and their width does not change.(Right panel) Same as in the left panel but in the presence of a finite spin-drag relaxation time [4]. Notice the spreading and attenuation of the packet as time progresses.

Non-equilibrium dynamics

Low-energy spin and charge excitations of 1D interacting fermions are completely decoupled and propagate with different velocities. These modes however can decay due to several possible mechanisms. In Ref. [4] we have exposed a new facet of spin-charge separation: not only the speeds but also the damping rates of spin and charge excitations are different. While the propagation of long-wavelength charge excitations is essentially ballistic, spin propagation is intrinsically damped and diffusive (see Fig. 1). We have also suggested that cold Fermi gases trapped inside a tight atomic waveguide offer the unique opportunity to measure the spin-drag relaxation rate that controls the broadening of a spin packet.

In Ref. [5] we have presented detailed investigations of the nonequilibrium dynamics of spin-polarized cold Fermi gases following a sudden switching-on of the atom-atom pairing coupling strength. Within a time-dependent mean-field approach we have shown that on increasing the imbalance it takes longer for pairing to develop, the period of the nonlinear oscillations lengthens, and the maximum value of the pairing amplitude decreases. As expected, dynamical pairing is suppressed by the increase of the imbalance. Eventually, for a critical value of the imbalance the nonlinear oscillations do not even develop. Finally, we have pointed out an interesting temperature-reentrant behavior of the exponent characterizing the initial instability (see Fig. 2).

Finally, in Ref. [6] we have presented a fully-microscopic theory to study the dynamics in 1D cold Fermi gas following a quench. Our approach, which is based on time-dependent current-density-functional theory, is applicable well beyond the linear-response regime and produces both spin-charge separation and spin-drag-induced broadening of the spin packets (see Fig. 3).

Fig. 2
(Left panel) The instability exponent as a function of spin-polarization and reduced temperature [5]. A finite instability exponent implies the development of pairing. A re-entrant region is clearly visible. (Right panel) Time-evolution of the distribution of condensed particles. As time evolves it pulses in synchronism with the nonlinear oscillations of the pairing function [5].

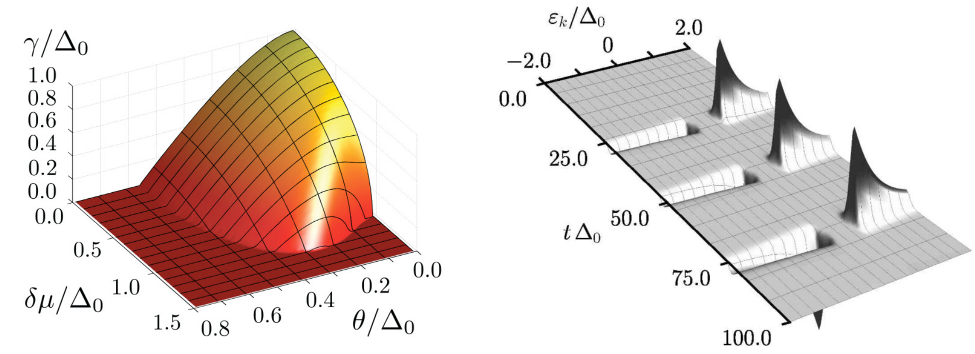
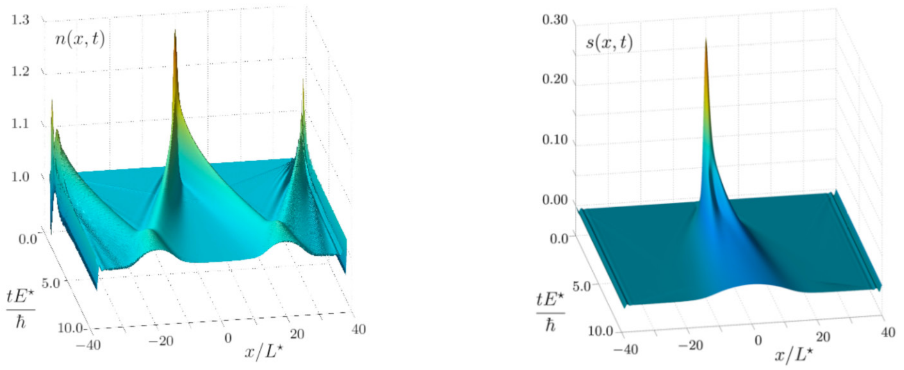


Fig. 3
(Left panel) A 3D plot of the space-time evolution of a density packet after a local quench [6]. Note that already at short times some density waves appear, coming from the sharp edges of the waveguide (Friedel oscillations): at larger time they mix with the original packet. (Right panel) Same as in the left panel but for a spin packet. We clearly see how the propagation in the spin channel is essentially diffusive [4,6].



References

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