Mass imbalanced Fermi mixtures with 2- and 3-body resonant interactions

PhD student: Elettra Neri
Tutor: Matteo Zaccanti

The investigation of strong interactions among fermions is of central importance for understanding a wealth of physical many-body systems, spanning a wide range of energies, from liquid Helium and solid-state systems up to quark matter.
Within this frame, ultracold dilute fermionic atoms emerge as an ideal quantum simulator tool, thanks to the high degree of control that is experimentally achievable over all the relevant parameters that set both the static and dynamical properties of such systems.

My PhD project aims at the realization and investigation of a novel ultracold mixture of Lithium and Chromium fermionic atoms. In such a mixture the Fermi surfaces mismatch due to the large mass asymmetry between the two species allows an unprecedented experimental exploration of superfluid phenomena beyond the standard Cooper pairing mechanism; a variety of still strongly debated phases can here emerge: for istance the Fulde-Ferrel-Larkin-Ovchinnikov (FFLO) phase, where pairs condense into a non-zero momentum state [1], leading to a spatially varying order parameter; and the breached pairing phase, where zero-momentum pairs would coexist with gapeless fermionic excitations [2].
Furthermore, for repulsive fermion-fermion interaction, the mismatch in the two Fermi surfaces is predicted to greatly facilitate the access to ferromagnetic phases, whose observation is extremely challenging in homonuclear Fermi mixtures [3].
The specific choice of a Li-Cr mixture is motivated by the extraordinary 3-body properties expected at the special Cr-Li mass ratio, unreachable with any other mixture. Here, few-body calculations predict the existence of a novel bound, or quasi-bound Cr-Cr-Li trimer state [4] that will allow for the first time the control of the elastic 3-body interactions, on top of the standard 2-body ones.

In the first part of my PhD project I will set up a new apparatus aiming at achieving simultaneous quantum degeneracy of ^{53}Cr and ^{6}Li atoms via laser techniques, starting from the design of the vacuum system and the optical setup.
To tune the 2-body interaction beteen Cr and Li in order to investigate all the previously mentioned phases, I will make use of the Feshbach resonance phenomenon, namely the dependence of the atom-atom collisional properties on an external magnetic field: the second part of my PhD will consist in the location of these suitable magetic regions, performing Li-Cr Feshbach spectroscopy via inelastic loss and radio-frequency techniques, and characterizing elastic collisions via cross thermalization experiments.
Similarly as for the atom-atom interactions, I will locate and characterize the Feshbach resonances between Cr atoms and Cr-Li dimers, which will allow me to control the 3-body Cr-(Cr-Li) interactions [5] and the appearence of the stable Cr-Cr-Li trimers.
In the last part of my PhD, I will investigate the ground state properties of Cr-Li mixtures as a function of the interspecies interaction, of the population imbalance and of the degree of quantum degeneracy: the emergence of FFLO phases or of breached pairing phases, as well as a macroscopic gas of fermionic trimers, will be unveiled by means of high-resolution imaging techniques, spatially- and momentum-resolved radio-frequency and Bragg spectroscopy techniques, measurement of collective oscillations and noise correlations measurements.

[1] P. Fulde, R. A. Ferrell, *Phys. Rev.* **135**, A550 (1964).

[2] W. V. Liu, F. Wilczek, *Phys. Rev. Lett.* **90**, 047002 (2003).

[3] P. Massignan, M. Zaccanti, G. M. Bruun, *Rep. Prog. Phys.* **77**, 034401 (2014).

[4] O. I. Kartavtsev, A. V. Malykh, *J. Phys. B* **40**, 1429 (2007).

[5] J. Levinsen, D. N. Petrov, *Eur. Phys. J. D* **65**, 67 (2011).