1D Quantum Liquid with High-Spin Fermions

A team of Italian and Australian scientists have realized one-dimensional (1D) quantum liquid with tunable spin in a paper published the prestigious Nature Physics on 3rd February, 2014. This realization has been made by the European Laboratory for Non-linear Spectroscopy (LENS) team led by Lenardo Fallani and Massimo Inguscio together with theorists Xia-Ji Liu and Hui Hu of Swinburne University of Technology in Melbourne.

The central aim of physics was to quantum emulate a simple text-book model for better understanding complex behaviours of strongly interacting fermions confined in low dimensions such as high-temperature superconductors, by using the table-top systems of ultracold atoms.

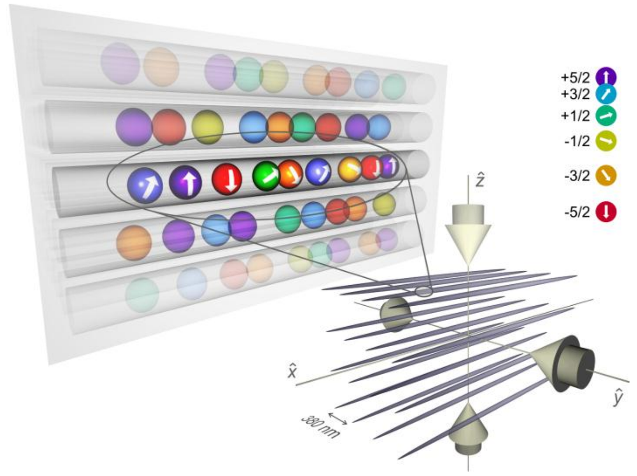

Fig. 1, By using two pairs of standing wave lights, ultracold ytterbium-173 atoms with six possible nuclear spin orientations can be trapped in a two-dimensional crystal-like structure, forming a bundle of independent one-dimensional quantum liquids with tunable spin.

Ultracold atoms is a rapidly developing field established following the Nobel Prize winning research on laser cooling of atoms in 1997 and Bose-Einstein condensation in 2001. At present, a cloud of atoms can be cooled down to incredibly low temperatures of a billionth of a degree Kelvin. At these temperatures, fermionic atoms – particles with spin one-half such as electrons and protons that are the building blocks of matter – can occupy quantum states one by one, precisely following the rule of quantum mechanics.

A unique aspect of ultracold atoms is their unprecedented controllability. A vast range of interactions, geometries and dimensions is possible: using the tool of Feshbach resonances and applying a magnetic field at the right strength, one can control very accurately the interactions between atoms, from arbitrarily weak to arbitrarily strong. By using the technique of optical lattices that trap atoms in crystal-like structures, one can create artificial one- or two-dimensional environments to explore how physics changes with dimensionality. As a result, the system of ultracold atoms appears to be a versatile tool for discovering new phenomena and exploring new horizons in diverse branches of physics.

At LENS, Leonardo Fallani and Massimo Inguscio and their colleagues have managed to cool fermionic ytterbium ^{173}Yb atoms down to near absolute zero, which are loaded in many independent quantum wires (see figure), and therefore realized an array of 1D quantum liquid. The use of the fermionic species ^{173}Yb is particularly interesting, as the atoms can be in six different internal states due to nuclear spin orientation. In more technical language, the atoms can interact within the SU(N) symmetry class with a tunable number N of spin components. The enlarged symmetries can lead to exotic ground states and topological excitations and hence this system can play a key role in future quantum technologies such as fault-tolerant quantum computers.

Theoretical scientists, Xia-Ji Liu and Hui Hu at the Centre for Quantum and Optical Science (CQOS), Swinburne University, have collaborated with the LENS team to understand the new experimental observation: the 1D high-spin fermionic system behaves like a spinless bosonic liquid in its dynamic property of collective density oscillations, in the large spin limit.

In a quantum emulation perspective, the creation of the new state of matter in this work, known as 1D strongly-correlated quantum liquid of ultracold fermions with tunable spin, promises an exciting new way to understand the counterintuitive 1D physics such as the complete separation of spin and charge excitations, which has been studied in theoretical physics over the past fifty years, and opens to the investigation of fundamental effects, ranging from spin dynamics to novel magnetic phases.