For the first time, researchers observe collective spin dynamics of ultra-cold fermions with large spins

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Understanding collective behavior of ultra-cold quantum gases is of great interest since it is intimately related to many encountered systems in nature such as human behavior, swarms of birds, traffic jam, sand dunes, neutron stars, fundamental magnetic properties of solids, or even super-fluidity or super-conductivity. In all of these everyday life examples, collective behavior plays a crucial role since all participating objects move, voluntarily or not, synchronously.

In a recent study coordinated by the Institute of Laser Physics, University of Hamburg - Germany, in collaboration with ICFO – the Institute of Photonic Sciences, researchers have observed, for the first time, the collective spin dynamics of ultra-cold fermions by analyzing the microscopic properties of the particles through their local collisions. The researchers were able to observe that at very low temperatures, close to absolute zero, the individual properties of each particle team up and behave coherently as a single identity in spin space. The results obtained from this study have recently been published in *Science*.

The "super" behavior of matter is actually a macro manifestation of the micro-laws of quantum mechanics. In the quantum micro-world, particles are divided into two main groups: bosons (e.g. photons) and fermions (e.g. constituents of matter such as electrons, protons, neutrons). The difference between these particles is basically their spin: bosons have integer spins and fermions have half-integer spins. Bosons behave collectively in spin rotation since they like to bundle up as friends and go with the flow. In the case of fermions, scientists did not know, up to now, whether these particles could behave the same way since they apparently are loners in this world.

Even more, if an atomic gas is cooled down to extremely low temperatures, bosons present the characteristics that many of them can occupy the same quantum state – they constitute a Bose condensate. In contrast, fermions have the particular characteristic of having only one particle per single state occupied, according to Pauli's exclusion principle.

To obtain ultra-cold fermions, the researchers trapped, via the use of a laser light, a quantum degenerate gas containing potassium atoms, cooled it down to very low temperatures and prepared different spin mixtures at very low magnetic fields to induce spin-changing dynamics. They were able to observe that when particles with very high spins collide between each other in local interactions, the resulting individual spins change. However, as a whole, they behave in a collective manner stabilizing the gas through long-lived, large-amplitude spin oscillations.

Hence, the research group led by ICREA Professor at ICFO Dr. Maciej Lewenstein came up with a novel effective theory that could explain correctly the experiment and discovered that the collective behavior is a quantum phenomenon which is very sensitive to perturbations (e.g. the effect completely disappears with a very slight change in the temperature). As Maciej Lewenstein states, "Fermions, due to Pauli's principle, are "individualists" - they do not like to behave in a same way. Nevertheless, here they team up to exhibit amazingly robust collective behavior. "

Through the controlled interplay of different fundamental processes that either stimulate or suppress the collective behavior, scientists are being able to have an in-depth understanding of the model system at work and therefore seek new pathways to study yet inaccessible exotic phenomena such as the creation of topological structures and textures in degenerate quantum gases with high spin or future applications such as quantum sensors for the smallest magnetic fields possible.

More information: J. S. Krauser, U. Ebling, N. Fläschner, J. Heinze, K. Sengstock, M. Lewenstein, A. Eckardt, C. Becker, Giant Spin Oscillations in an Ultracold Fermi Sea, *Science* 10 January 2014: Vol. 343 no. 6167 pp. 157-160, DOI: 10.1126/science.1244059

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