Physics/Astrophysics

Planning Group Members: Frank Goehmann and Takaaki Koga

Cold quantum gasses

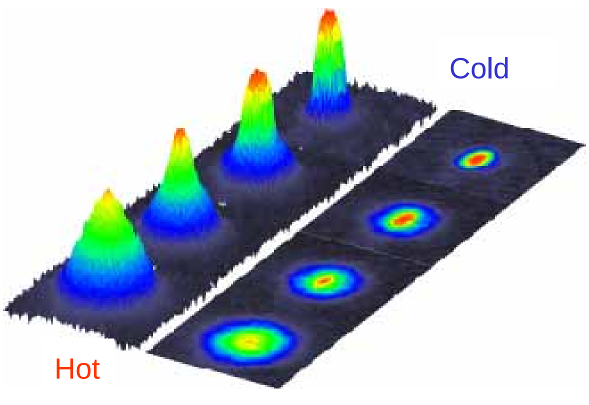
<u>Speaker:</u>

Yoshiro Takahashi, Kyoto University

Title: Novel Cold Atomic Gas – from ultra high resolution laser spectroscopy to scalable quantum computation

1. Introduction

In a hot and dilute gas phase neutral atoms are randomly and independently moving at relatively high speed and their statistical behaviors can be interpreted by a classical theory. If the temperature of the gas becomes lower than some critical value by elaborate laser cooling techniques, however, the inherent quantum mechanical property manifests iteself. In the case of bosonic atoms in which total number of electrons and nucleons is even, wave nature of each atoms coherently builds up to an emergence of a macroscopic matter wave which is called a Bose-Einstein condensation. The false color velocity distributions of the atoms around the critical temperature are depicted below.



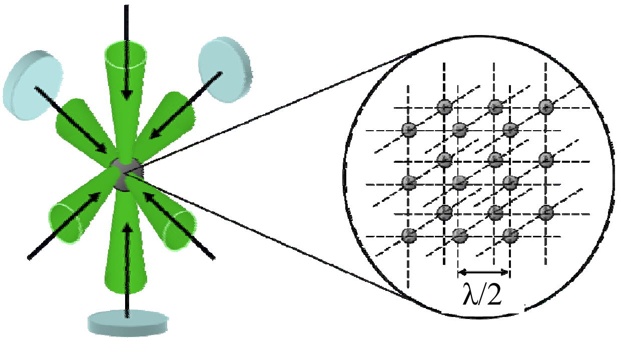
In the case of fermionic atoms in which total number of electrons and nucleons is odd, on the other hand, a fundamental quantum mechanical principle of Pauli exclusion principle excludes the possibility of occupation of the same quantum state by more than two identical fermions. This results in a quantum degenerate state of Fermi degeneracy where the atoms are only populated in the states below the characteristic energy of so called Fermi energy.

2. Experiment

While alkali-atoms are most familiar in the study of cold quantum gas, we recently work with ytterbium (Yb) atoms since the Yb atoms have many unique advantages such as the existence of ultra-narrow optical transitions and a rich variety of isotopes, that is, two fermions and five bosons which will extend the variety of the study of the quantum gas. So far, we have succeeded in creating Bose-Einstein condensation [1] and Fermi-degeneracy [2] and their mixture of Yb atoms. Such quantum degenerate gases have recently been successfully probed with an ultra high-resolution laser spectroscopy using ultra-narrow optical transitions to reveal the quantum many-body properties.

3. Towards Scalable Quantum Computation

The success of the ultra-high resolution spectroscopy of quantum degenerate gases has recently led us to propose a novel scheme of scalable quantum computation using cold fermionic Yb atoms in an optical lattice. An optical lattice is a sub-micron scale periodic potential



for atoms produced by a standing wave of laser light depicted above. Two internal quantum states in each atom loaded in one optical lattice site is regarded as a fundamental quantum bit in this quantum computer, and an individual addressing can be possible by a spectral addressing under a magnetic field gradient, the principle of which is essentially the same as the magnetic resonance imaging.

Conclusion

Recent advance in the technique of cooling neutral atoms enables us to produce various quantum degenerate gases. These systems do not suffer from problems like impurities and lattice defects, and have high controllability. They are, therefore, ideal for basic research of quamtum many-body physics as well as for building an ultimate quantum device like a quantum computer.

References

[1] Y. Takasu, K. Maki, K. Komori, T. Takano, K. Honda, M. Kumakura, T. Yabuzaki, and Y. Takahashi, “Spin-Singlet Bose-Einstein Condensation of Two-Electron Atoms”, Phys. Rev. Lett. **91**,040404-1-4 (2003).

[2] T. Fukuhara, Y. Takasu, M. Kumakura, and Y. Takahashi, “Degenerate Fermi Gases of Ytterbium”, Phys. Rev. Lett. **98**., 030401-1-4(2007).