清华大学高等研究院 – 冷原子物理系列讲座

地点: 高等研究院，科学馆一楼报告厅

报告人: Prof. Yvan Castin
LKB-ENS, Paris, France

Lectures 1 and 2: Temporal coherence of atomic Bose-Einstein condensates, and application to spin squeezing

The recent experimental progress in the physics of Bose-condensed atoms implies that both difficult fundamental issues and ambitious quantum applications may be considered.

A key example of a fundamental issue is the coherence time of a Bose-Einstein condensate at finite temperature. As we will explain, the problem is quite subtle, which explains why various works in the past reached opposite conclusions. In particular, contrarily to what suggests the analogy with the optical laser, strict diffusion of the condensate phase is not what generically happens, due to the fact that the atomic gases are systems well isolated from the environment. In the lecture, we will present elementary theoretical methods allowing one to obtain a conclusive view, from Bogoliubov approach to ergodic theory, the eigenstate thermalisation hypothesis and quantum kinetic theory. Comparison to classical fields simulations will be presented.

A key example of an ambitious quantum application is spin squeezing. Spin squeezed states can increase the signal-to-noise ratio in atomic clocks, since one component of the collective spin of the N two-level atoms has, in the direction transverse to the mean spin, reduced fluctuations as compared to the standard quantum limit. As shown by Kitagawa and Ueda in the nineties, spin squeezed states result from a non-linear dynamics of the spin, and two experimental groups have successfully implemented this idea in interacting atomic Bose-Einstein condensates. Whereas spin squeezing is still limited in the experiments by technical noise, we anticipate that finite temperature effects, that require a multimode description of spin squeezing, will eventually become dominant. In the lecture, we will explain in elementary terms how to develop such an analytically multimode treatment of spin squeezing, and we will show that, in the thermodynamic limit, the gain in the clock signal-to noise ratio, rather than diverging as N^(1/3) as in Kitagawa and Ueda's two-mode model, saturates to a finite value that will be evaluated and compared to semi-classical field simulations.

Lectures 3 and 4: Unitary gases and the Efimov effect

Thanks to the magnetic Feshbach resonance technique, experimentalists can now prepare strongly interacting gases, that is the s-wave scattering length between the atoms becomes larger in absolute value that the mean interparticle distance. For two-component Fermi gases, this has allowed to realize the crossover of a BCS state of Cooper pairs to a Bose-Einstein condensate of dimers. In the lectures, we shall concentrate on a particularly fascinating point of the crossover, where the s-wave scattering length is infinite: The scattering amplitude between two atoms then reaches at all relevant momenta the maximal modulus allowed by quantum mechanics, this is the so-called unitary limit, hence the name of "unitary gas", which is a maximally interacting gas in this respect.

The unitary gas has intriguing scale-invariance properties that we shall review. After introduction of the zero-range model (or Wigner-Bethe-Peierls model), that replaces interaction by contact conditions on the wavefunction, we shall obtain simple consequences of scaling invariance, then more elaborate dynamical consequences, such as the SO(2,1) hidden symmetry for a trapped unitary gas, that results from the existence of an undamped breathing mode and that implies vanishing of the bulk viscosity of the homogeneous system.

Yet another, and fruitful view of the hidden symmetry, is the fact that the many-body wavefunction separates in hyperspherical coordinates. This allows to naturally introduce the concept of n-body Efimov effect (the original Efimov effect corresponding to n=3): such an effect takes place when the effective n-body force on the hyperradius is attractive. This destroys the scaling invariance of the unitary gas and leads to a geometric spectrum of n-mers with an accumulation point at zero energy. Whereas the original Efimov effect (predicted by Efimov in the early seventies and recently confirmed experimentally with bosons) corresponds to n=3, we will explain that an extended Efimov effect with n=4 is predicted to take place for three identical fermions and a mobile impurity, when the fermion-to-impurity mass ratio is in the appropriate interval.

In the last part of the lectures, we shall explain how to go beyond the zero range theory. First in the absence of the Efimov effect: we will explain how the leading order deviations of the eigenenergies from their unitary-limit values (due to the finite interaction range) can be deduced from generalized Tan relations, and how they provide a mechanism for zero-temperature damping of the unitary gas breathing mode. Second in the presence of the Efimov effect: we will address the fundamental question of how the Efimov trimers are born, when there exists a control parameter allowing one to continuously switch on the n=3 Efimov effect, that is to move from a situation with no trimer states to an infinite number of trimer states. An analytical answer will be given for two identical fermions interacting with a mobile impurity on a narrow Feshbach resonance, where the control parameter is the fermion-to-impurity mass ratio.

Lectures 1 and 2
April 8, 2013, Monday,
2:30-3:30, 4:00-5:00

Lectures 3 and 4
April 9, 2013, Tuesday,
2:30-3:30, 4:00-5:00

Prof. Yvan Castin

Yvan Castin was born in 1966. He is a Director of Research at French CNRS and a former student of the Ecole normale superieure in Paris (France). He has done his doctoral studies on the quantum theory of laser cooling under the direction of Jean Dalibard and Claude Cohen-Tannoudji (1988-1992). He has been working on the theory of bosonic and fermionic quantum gases at Laboratoire Kastler-Brossel in the Ecole normale superieure since 1995. He has obtained the Jacques Herbrand Prize of the French Academy of Sciences in 2001.