Physics and Mathematics of Bose-Einstein Condensates

Dijon, February 24–26, 2025

The event will take place in the "Salle René Baire" on the 4th floor of the A-wing (mathematics institute).

Programme

Monday, February 24th

- 9 : 30 – 10 : 30 Bruno Peaudecerf
  Experiments with Bose-Einstein condensates: from atom cooling to quantum control and simulation.
- 10 : 30 – 11 : 00 Coffee break
- 11 : 00 – 12 : 00 Marcin Napiórkowski
  BEC and effective theories – a mathematical perspective.
- Lunch
- 14 : 00 – 15 : 00 Marcin Napiórkowski
  BEC and effective theories – a mathematical perspective.
- 15 : 00 – 15 : 20 Siegfried Spruck
  Derivation of the Effective Dynamics for the Bose Polaron
- 15 : 25 – 15 : 45 Nicolas Ombredane
  Optimal Control for Quantum Sensing with Bose-Einstein condensates
- 16 : 00 – 16 : 30 Coffee break
- 16 : 30 – 17 : 30 Bruno Peaudecerf
  Experiments with Bose-Einstein condensates: from atom cooling to quantum control and simulation.
- 18 : 00 Reception.

Tuesday, February 25th

- 9 : 30 – 10 : 30 Bruno Peaudecerf
  Experiments with Bose-Einstein condensates: from atom cooling to quantum control and simulation.
- 10 : 30 – 11 : 00 Coffee break
- 11 : 00 – 12 : 00 Eugenio Pozzoli
  Controllability of Schrödinger equations and application to quantum rotors.
- Lunch
- 14 : 00 – 14 : 20 Asbjorn Lauritsen
  Ground state energies of dilute Fermi gases
- 14 : 25 – 14 : 45 Jingjun Zhu
  Control of nonlinear quantum systems
- 14 : 50 – 15 : 10 Adrien Tendani-Soler
  Existence and non-existence of travelling waves for a polaron equation
- 15 : 15 – 15 : 35 Charbel Karam
  Ultracold Molecules, from Dilute to Quantum Degenerate Gases
- 15 : 40 – 16 : 00 Ruikang Liang
  Ensemble control of n-level quantum systems with a scalar control
- 16 : 00 – 16 : 30 Coffee break
- 16 : 30 – 17 : 30 Marcin Napiórkowski
  BEC and effective theories – a mathematical perspective.

Wednesday, February 26th

- 9 : 30 – 10 : 30 Eugenio Pozzoli
  Controllability of Schrödinger equations and application to quantum rotors.
- 10 : 30 – 11 : 00 Coffee break
- 11 : 00 – 12 : 00 Eugenio Pozzoli
  Controllability of Schrödinger equations and application to quantum rotors.
- Lunch

Abstracts

Siegfried Spruck

Derivation of the Effective Dynamics for the Bose Polaron

We consider the dynamics of a dense quantum gas consisting of N bosons evolving in $\mathbb{R}^3$ in the presence of an impurity particle in the mean-field scaling with initially high density and large volume of the gas. In the initial state of the system almost all Bosons are in the Bose-Einstein condensate, with a few excitations. For this system we derive from the microscopic dynamics in the limit of large densities and volumes the effective description by a quantum field theory modelled by the Bogoliubov-Fröhlich Hamiltonian and thus prove the existence of a quasi-particle, the Bose polaron.

Nicolas Ombredane

Optimal Control for Quantum Sensing with Bose-Einstein condensates

Bose-Einstein Condensates (BEC) constitute a highly controllable platform well-suited for quantum simulations and quantum metrology. Quantum Optimal Control (QOC) has been implemented [1] to manipulate the quantum state of a BEC in a 1D optical lattice. In the context of quantum sensing, the sensitivity of the state evolution to a parameter can be characterized in the formalism of Fisher information, which sets a lower bound on the attainable precision for the measurement of the parameter. We can then investigate how quantum control can allow to optimize and saturate this bound. In this presentation, I will discuss how we apply this approach to the measurement of an external force applied to a BEC in an optical lattice in the Toulouse experiment, and present preliminary results.

[1] N. Dupont et al., PRX QUANTUM. 2, 040303 (2021)

Asbjorn Lauritsen

Ground state energies of dilute Fermi gases

Recently much interest has been given to the study of dilute interacting Bose and Fermi gases. For both the Bose gas and Fermi gas with spin the ground state energy densities differ to leading order from that of the free (non-interacting) gases by a term of order $a_s\rho^2$ with a_s the s-wave scattering length of the repulsive interaction. In contrast, for a spin-polarized Fermi gas, the difference is instead of order $a_p\rho^{8/3}$ with a_p the p-wave scattering length. I will discuss some intuition behind these results and in particular how the p-wave term is related to the Pauli exclusion principle. Joint work with Robert Seiringer.

Jingjun Zhu

Control of nonlinear quantum systems

We explore the fast and robust control of nonlinear Kerr-type quantum systems by two-stage optimal inverse engineering, which has potential application for controlling of motional states of weakly interacting BECs in an accelerating optical lattice. We first provide the exact resonant solution in terms of a Jacobi elliptic integral, referred to the so-called 2K-pulse and relavant to nonlinear Rabi oscillations. This explicitly elucidates the obstructions above a certain critical value of the nonlinearity strength in the regime of non-adiabaticity. Given the additional freedom of parameters, we next combine robust inverse optmization (RIO) developed for linear systems to dynamically compensate third-order nonlinearities. We show that the resulting nonlinear robustness dramatically surpasses the one of its linear counterpart for a moderate nonlinearity.

Adrien Tendani-Soler

Existence and non-existence of travelling waves for a polaron equation

TBA

Charbel Karam

Ultracold Molecules, from Dilute to Quantum Degenerate Gases

Ultracold polar molecules have emerged as a powerful platform for exploring many-body quantum physics, thanks to their rich internal structure and strong dipolar interactions. In particular, bialkali molecules, which possess a strong permanent electric dipole moment in their own frame, provide an exciting avenue for studying dipolar quantum gases, where the macroscopic effects of the dipolar interactions are significantly stronger than those observed in atomic systems with magnetic dipoles. This has sparked considerable interest in applications ranging from quantum simulation to ultracold chemistry. However, a major challenge has hindered progress in the field: when these molecules are prepared in their absolute ground state and confined in traps, they rapidly undergo collisional losses, preventing any further application.

In this talk, we will discuss the key challenges faced by the community in controlling these losses and how recent breakthroughs has led to the creation of the first Bose-Einstein condensate of ground-state bialkali molecules. Along the way, we will highlight the experimental and theoretical advances that have shaped this rapidly evolving field.

Ruikang Liang

Ensemble control of n-level quantum systems with a scalar control

In this talk, I will discuss how a general bilinear finite-dimensional closed quantum system with dispersed parameters can be steered between eigenstates. We show that, under suitable conditions on the separation of spectral gaps and the boundedness of parameter dispersion, rotating wave and adiabatic approximations can be employed in cascade to achieve population inversion between arbitrary eigenstates.