Workshop "Dynamics of quantum gases in one dimension"

September 28-29, 2010 – Orsay

(Building 100, room « salle des conseils »)

http://lptms.u-psud.fr/Dynamics_of_quantum_gases_in_one_dimension/

PROGRAM

	28 September 2010
09.00 - 09.10	Introduction
09.10 - 10.00	Vadim Cheianov (Lancaster University, UK)
10.00 - 10.50	Dimitri Gangardt (Birmingham University, UK)
10.50 - 11.20	Coffee break
11.20 - 12.10	Carlo Sias (Cambridge University, UK)
12.10 - 13.00	Klaasjan van Druten (Amsterdam University, NL)
13.00 - 14.30	Lunch
14.30 - 15.20	Sebastian Hofferberth (Harvard University, USA)
15.20 - 16.10	Elmar Haller (Innsbruck University, Austria)
16.10 - 16.40	Coffee break
16.40 - 17.05	Tetsu Takekoshi (Innsbruck University, Austria)
17.05 - 17.55	Dmitry Petrov (LPTMS, France)
17.55 - 18.20	Anna Minguzzi (LPMMC, France)
19.00 -	Dinner at the restaurant "Le Gramophone"
	29 September 2010
09.00 - 09.50	Isabelle Bouchoule (LCFIO, France)
09.50 - 10.40	Aurélien Perrin (Vienna University of Technology, Austria)
10.40 - 11.10	Coffee break
11.10 - 12.00	Igor Mazets (Vienna University of Technology, Austria)
12.00 - 12.50	David Clement (LENS, Italy)
12.50 -	Lunch

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TITLES AND ABSTRACTS

28 September 2010

[09.10 - 10.00] Vadim Cheianov (Lancaster University, UK)

Edge singularities in response functions of one-dimensional quantum fluids.

One of the distinctive features of a quantum fluid in one spacial dimension is the absence of a dissipative response to any periodic perturbations with frequency below some momentum-dependent threshold value. Recently, a lot of progress has been achieved in theoretical understanding of the behavior of the response functions of the fluid near the frequency threshold. In this talk I shall discuss how the singularities of the response functions near the threshold frequency can be understood within a simple effective model, describe the methods for the calculation of the power-law threshold divergences and explain their relationship to the experimentally observable propagation of local perturbations.

[**10.00 - 10.50] Dimitri Gangardt (Birmingham University, UK)**

Effective low energy dynamics of quantum impurity

Understanding of interactions between quantum liquids and impurities is important for studying superfluid flow in disordered media in 1d. Impurities create nonlinear disturbances in the quantum liquid with a complicated dynamics. For low enough temperatures and velocities of the liquid the description can be simplified and leads to an universal Hamiltonian describing interactions of the dressed impurities with long wavelength phonons. The phenomenological parameters of this Hamiltonian can be determined semiclassically in the case of weak interactions. In this talk we review this method and apply it to study dissipative dynamics of dark solitons, which may be regarded as mobile impurities. Our main findings are as follows. Unless protected by the exact integrability, solitons are subject to dissipative forces, originating from a thermally fluctuating background. At low enough temperatures T background fluctuations (phonons) should be considered as being quantised. Since the soliton velocity V is always smaller than the speed of sound c, emission of a single phonon is forbidden by the energy and momentum conservation, i.e. by Landau criterion. The leading allowed process is the Raman two-phonon scattering, where one thermal phonon is absorbed and another one reemitted. This enables us to calculate finite lifetime of the solitons $\tau \sim T^{-4}$. We show that the prefactor in the expression for the life-time depends crucially on integrability properties of the quantum liquid model. We also find that the coherent nature of the quantum fluctuations leads to enhanced mutual friction of solitons due to the superradiation of phonons. Our results are of relevance to current experiments with ultracold atoms, while the approach may be extended to solitons in other media.

[1] D. M. Gangardt and A. Kamenev, Phys. Rev. Lett. 102, 070402 2009.
[2] D. M. Gangardt and A. Kamenev, accepted for publication in Phys. Rev. Lett.

[11.20 - 12.10] Carlo Sias (Cambridge University, UK)

Impurities in a Bose gas

In the first part of my talk I will show an experimental investigation on the non-equilibrium transport of spin impurity atoms through a one-dimensional, strongly interacting Bose gas. The initially well localized impurities are accelerated by a constant force, very much analogous to electrons subject to a bias voltage, and undergo scattering with the atoms in the Tonks-Girardeau gas. The motion of the impurity atoms and the excitations induced in the one dimensional bath are investigated in situ by use of a tomographic technique. We observe a very complex non-equilibrium dynamics, including the emergence of large density fluctuations in the remaining Bose gas, and multiple scattering events leading to dissipation of the impurity's motion. In the second part of my talk I will show a different approach to the problem of impurities in a Bose gas, by immersion of a single trapped ion in a Bose-Einstein condensate. We demonstrate the independent control over the two systems, study the fundamental interaction processes, and observe sympathetic cooling of a single ion in an ultracold bath of neutral atoms. Additionally, we characterize elastic and inelastic atom-ion collisions and measure the energy-dependent reaction rate constants. Our experiment opens possibilities for continuous cooling of a quantum computer and for exploring entanglement in hybrid quantum systems.

[12.10 - 13.00] Klaasjan van Druten (Amsterdam University, NL)

Controlling state-dependent interactions and spin motion in a one-dimensional two-component Bose gas

Ultracold gases offer new approaches to explore quantum many-body physics with unique control over key parameters such as interactions and dimensionality. Use of the internal atomic degrees of freedom ("spin") allows the study of, e.g., spin waves and spin-charge separation.We create coherent superpositions of both spin and motional degrees of freedom and probe spin dynamics of a one-dimensional (1D) Bose gas of 87Rb on an atom chip. We observe interaction-driven dynamics of one spin component by mean-field interaction with another component, directly related to the effective 1D interaction strength. We demonstrate experimental control over the 1D interaction strengths through state-selective radio-frequency dressing. The dynamics are altered by tuning the trapping potential in a state-dependent way as a means to modify the inter-and intra state interactions. This enables, for instance, access to the point of spin-independent interactions where the local spin velocity vanishes and exact quantum many-body solutions are available and to the point where spin motion is frozen.

[14.30 - 15.20] Sebastian Hofferberth (Harvard University, USA)

Interacting atoms and photons - two experimental realizations of one-dimensional systems

The standard experimental approach to realize one-dimensional (1d) systems with cold atoms is based on standing wave optical traps. In this way, ensembles of 1d-traps can be realized which offer great flexibility and tunability of atomic interactions. The inherent disadvantage of this system is that one usually can only measure ensemble averages. In this talk, I will discuss two alternative approaches which circumvent this problem and consequently yield access to observations not possible in optical lattices. Firstly, I will discuss weakly interacting gases in magnetic micro-traps on an atom chip. This system consists of exactly one or two 1d-traps, which offers the unique ability to measure the local phase of the Bose gas via interference. In particular, I will discuss an experiment measuring the full counting statistics of the phase fluctuations in weakly interacting 1d quasi-condensates. Secondly, I will present a new system consisting of cold atoms inside a hollow-core photonic crystal fiber. In this case, we persue a completely new approach of investigating a system of strongly interacting polaritons, which contain both photonic and atomic components. The ability to convert correlations between these quasi-particles into photon statistics which can be measured with the usual quantum optics techniques offers wholly new access to strongly interacting systems. I will discuss our experimental progress towards such a 1d photon gas as well as practical and theoretical limitations of this approach.

[15.20 - 16.10] Elmar Haller (Innsbruck University, Austria)

Interaction regimes and quantum phase transitions in 1D systems

I will report on our current experiments with quantum gases of strongly interacting atoms confined to one-dimensional (1D) geometry. The external confinement strongly affects the atomic scattering process and gives rise to a new type of scattering resonances, so-called confinement-induced resonances [1]. One such resonance allows us to control inter-particle interactions in 1D and to access the regimes of strong repulsion and attraction. In particular, we observe the formation of a highly-correlated quantum many-body phase called the Super-Tonks-Girardeau gas [2]. This excited phase in 1D is stabilized in the presence of attractive interactions by maintaining and strengthening quantum correlations across the confinement-induced resonance.
In a second experiment we drive a novel type of quantum phase transition, by adding a shallow periodic potential to a Tonks-Girardeau gas. For sufficiently strong interactions, the transition is induced by adding an arbitrarily weak optical lattice along the longitudinal direction of the 1D system, leading to immediate pinning of the particles. We map out the complete phase diagram of this superfluid to Mott-insulator transition and find that our measurements in the strongly interacting regime agree well with a quantum field description based on the exactly solvable sine-Gordon model [3].

[1] E. Haller, M.J. Mark, R. Hart, J.G. Danzl, L. Reichsollner, V. Melezhik, P. Schmelcher, H.-C. Nagerl, Phys. Rev. Lett. 104, 153203 (2010).

[2] E. Haller, M. Gustavsson, M.J. Mark, J.G. Danzl, R. Hart, G. Pupillo, H.-C. Nagerl, Science 325, 1224 (2009).

[3] E. Haller, R. Hart, M.J. Mark, J.G. Danzl, L. Reichsollner, M. Gustavsson, M. Dalmonte, G. Pupillo, H.-C. Nagerl, Nature 66, 597 (2010).

[16.40 - 17.05] Tetsu Takekoshi (Innsbruck University, Austria)

Rb/Cs mixtures and ro-vibrational ground state RbCs molecules: possible 1D experiments"

We explore possible 1D experiments with a degenerate Rb/Cs mixture. Feshbach resonance and binding energy measurements are being used to develop a coupled-channel model for the 87Rb Cs system. Our progress towards the formation of high phase-space density ground state RbCs, as well as possible dipolar 1D systems will also be discussed.

[17.05 - 17.55] Dmitry Petrov (LPTMS, France)

Parametric excitation of a 1D gas in integrable and non-integrable cases

We study the response of a highly excited 1D gas with point-like interactions to a periodic modulation of the coupling constant. We calculate the corresponding dynamic structure factors and show that their low-frequency behavior differs dramatically for integrable and non-integrable models. Non-integrable systems are sensitive to excitations with frequencies as low as the mean level spacing, whereas much higher frequencies are required to excite an integrable system. This effect can be used as a probe of integrability for mesoscopic 1D systems and can be observed experimentally by measuring the heating rate of a parametrically excited gas.

[17.55 - 18.20] Anna Minguzzi (LPMMC, France)

Stirring a strongly interacting 1D Bose gas on a ring

We consider an interacting Bose fluid confined in a ring geometry. We study the dynamical properties of the fluid induced by a moving barrier-potential as a probe of imperfect superfluid behavior of the 1D Bose system. [1,2] We concentrate in particular on the Tonks-Girardeau limit of impenetrable bosons, where we provide an exact solution for the dynamical evolution at all times and arbitrary velocity of the barrier. [3]

[1] G.E. Astrakharchik and Lev Pitaevskii, Phys. Rev. A 70, 013608 (2004)
[2] R. Citro, A. Minguzzi, and F.W.J. Hekking, Phys. Rev. B 79, 172505 (2009)
[3] C. Schenke, A. Minguzzi, and F.W.J. Hekking, in preparation

29 September 2010

[09.00 - 09.50] Isabelle Bouchoule (LCFIO, France)

What we learn from density fluctuation measurement : 1D/3D crossover and three-body correlations in weakly interacting Bose gases

Density fluctuations, related to correlation functions, constitute an interesting probe of quantum gases. This is particularly true for 1D gases where fluctuations govern the physics. In our experiment, we measure density fluctuations of Bose gases strongly confined in the transverse directions. We probe the transition towards quasi-bec and investigate the 1D/3D dimensional crossover. For deeply 1D gases, we reached the quantum fluctuation regime where fluctuations are sub-shotnoise. Finally, we measure the third moment of atom-number fluctuations, a quantity related to the three body correlation function.

[09.50 - 10.40] Aurélien Perrin (Vienna University of Technology, Austria)

One-dimensional quasi-condensate in and out of equilibrium

Dimensionality strongly affect the physics of Bose gases. Weakly interacting Bose gases in the 1D/3D crossover are characterized by thermally activated phase fluctuations. In free expansion these fluctuations convert into density fluctuations that can be observed experimentally. The comparison of the behavior of the density correlation function with a recent theoretical model have allowed us to measure the temperature of quasi-condensates.
Controlled transverse dipole excitations of a 1D quasi-condensate allow to bring the majority of the particles of the system in their first transverse excited state. Due to parity rules, the relaxation of these excitations by interatomic collisions leads to the creation of pairs of longitudinal excitations with correlated momentum. Using a novel fluorescence detector, we

have been able to observe the squeezing of the fluctuations of the relative population of the pairs modes.

[11.10 - 12.00] Igor Mazets (Vienna University of Technology, Austria)

Noise and correlations in coupled 1D quasicondensates: description by a stochastic Ornstein-Uhlenbeck process

A new method to describe noise and correlations in 1D degenerate bosonic systems is proposed. In a quasicondensate of atoms with repulsive interactions (for example, rubidium-87), density fluctuations are suppressed, and noise and correlations are determined mainly by phase fluctuations. Taking into account the autocorrelation function (first obtained by Whitlock and Bouchoule) of the relative phase between two 1D quasicondensates in a double-well potential and the Gaussian distribution of fluctuations, we elaborate a description of these fluctuations by a stochastic (Ornstein-Uhlenbeck) process that develops in space, along the major axis of the trap. The ratio of the temperature to the linear atomic density defines the "diffusion" and inter-well coupling provides "friction". The method is found to be computationally fast and efficient, especially for longitudinally inhomogeneous (finite-size) atomic clouds. Applications of the stochastic-process description to full characterization of coupled quasicondensates at equilibrium in experiment is discussed.

[12.00 - 12.50] David Clement (LENS, Italy)

Probing correlated 1D Bose gases by inelastic light scattering

In condensed matter physics, inelastic scattering of waves or particles provided a very powerful method to characterize the systems under study. Neutron scattering allowed the first experimental observation of condensate in superfluid He4. As soon as experiments on ultracold quantum gases in optical lattices started to simulate many-body systems, theoretical papers appeared proposing to measure their dynamical structure factor through inelastic light scattering. In general, inelastic light scattering allows to measure correlation functions which could identify different many-body states. The response of the system to an excitation with frequency v and momentum p is probed thanks to a two photon transition coupling two states with the same internal degrees of freedom (Bragg spectroscopy). We will report on the experimental investigation of inelastic light scattering from an array of 1D ultracold samples of 87Rb atoms. We investigated phase-coherence properties of 1D gases, measuring coherence lengths well below one micron. We performed as well investigations in an optical lattice across the superfluid to Mott Insulator transition in the linear regime where the excitation in the lowest band is proportional to the dynamical structure factor. Besides the frequency regions attributed to the superfluid and insulator phases, the system can be excited suggesting the presence of temperature effects and the appearance of a gapped mode in the strongly correlated superfluid regime. Finally, we also investigated transitions toward excited bands coupling the many-body insulator state to free particles states and giving information on single-particle spectral functions.