BECosmology

Non-equilibrium Bose-Einstein condensates and its application to Cosmology

University of Nottingham, Nottingham, UK
School of Mathematical Sciences & School of Physics & Astronomy

Date: 23/24 June 2014

Organizers: Peter Kruger • Bill Unruh • Silke Weinfurtner

Sponsors: Fqxi, School of Mathematical Sciences, and School of Physics & Astronomy

List of participants

John Barrett • Tom Barrett • Clare Burrage • Ed Copeland • Antonin Coutant • Daniele Faccio • Jorge Ferreras • Andreas Finke • Juan Garrahan • Ed Hinds • Ted Jacobson • Piyush Jain • Dieter Jaksch • Claus Kiefer • Peter Kruger • Tim Langen • Emanuele Levi • Jorma Louko • Fedja Orucevic • Parentani Renaud • Wolfgang Rohringer • Joerg Schmiedmayer • Thomas Sotiriou • Andrea Trombettoni • Bill Unruh • Silke Weinfurtner • Chris Westbrook

TITLE & ABSTRACTS

All presentations are 45 minutes + 15 discussions.

Clare Burrage

DETECTING DARK ENERGY IN THE LABORATORY

Attempts to explain the current acceleration of the expansion of the universe typically introduce new scalar fields that we call dark energy. I will describe how these fields interact with standard model particles and explain why we expect the strength of these interactions to vary depending on the environment. This will lead us to propose new atomic tests for dark energy, with sensitivity many orders of magnitude higher than previous laboratory searches.

Ed Copeland

INFLATION IN LIGHT OF BICEP2

We look at the inflationary paradigm in light of the recent results published by the BICEP2 collaboration. Does it really confirm inflation occurred in the early universe ?

Daniele Faccio

ANALOGUE GRAVITY IN PHOTON FLUIDS - CHALLENGES AND OPPORTUNITIES

Negative (defocusing) third order optical nonlinearities give rise to a repulsive force between photons, which under appropriate conditions behave like a fluid. If the nonlinearity is local, superfluid properties are observed and it is possible to build analogues for gravitational systems that bear a strong resemblance to similar systems in BECs. However, many common optical media with defocusing nonlinearity are also nonlocal, i.e. the response at one spatial point depends on the system properties (light beam intensity) at other neighbouring points. This has several consequences. The dispersion relation returns to its quadratic form and is only linear only for extremely low frequencies. Moreover, instabilities within the system are strongly affected and may even be suppressed. However, other opportunities arise for example for observing optical wave turblulence with a long range interaction and Vlasov-like dynamics that exhibit a close analogy to the formation of large scale structures in the universe (e.g. galaxies) as a consequence of the long-range nature of gravity.

Piyush Jain

DAMPING AND THERMALIZATION IN A PARAMETRICALLY EXCITED BOSE GAS

We investigate the nonequilibrium dynamics of a weakly interacting Bose gas subject to either an interaction quench or parametric driving of the interaction strength. In both cases we compare the linearized Bogoliubov theory with the results of classical field simulations based on the truncated Wigner approximation. For the interaction quench we find a prethermalized state is predicted within the linear theory but that the simulations lead to thermalization on a longer time scale. For a quench to smaller interactions starting at a temperature less than the chemical potential, the initial field, which exhibits subpoisson statistics in the two mode variance for opposite momenta modes, becomes superpoisson as the field thermalizes. In contrast, for a quench to larger interactions starting at a temperature greater than the chemical potential, one can drive the system from superpoisson to subpoisson. In the case of parametric driving, we compare analytic predictions for the quasiparticle populations and two mode variance with simulation results. We find quasiparticle damping results in a loss of any correlation created via the parametric process after the driving field is switched off. A particularly interesting regime occurs when the driving amplitude is sufficiently small that the

system is critically damped. These predictions have implications for both analogue gravity and quantum metrology experiments.

Dieter Jaksch

TENSOR NETWORK THEORY AND APPLICATIONS IN NON-EQUILIBRIUM COLD ATOM PHYSICS

Recent progress in controlling and probing ultracold atoms make coherent non-equilibrium quantum dynamics of strongly correlated many particle systems experimental accessible. This enables the study of so far largely unexplored and novel physics with potential applications e.g. in designing quantum materials and in quantum information processing. It also brings with it theoretical challenges as many of the standard methods that are used in thermal equilibrium fail. In this talk I will present Tensor Network Theory (TNT) as a possible set of methods to gain insights into non-equilibrium many particle quantum physics. TNT allows to systematically go beyond mean-field theories and its error is controllable. TNT algorithms such as density matrix renormalization group (DMRG) can be used to study ground states while its time dependent variant t-DMRG is often well suited to study non-equilibrium quantum dynamics. I will discuss examples of TNT calculations that give insights into the non-equilibrium dynamics in systems of ultracold atoms. The TNT software used for these calculations can be accessed at www.tensornetworktheory.org.

Claus Kiefer

QUANTUM-TO-CLASSICAL TRANSITION IN COSMOLOGY

Assuming that the Universe is fundamentally described by quantum theory, it is of great importance to understand the emergence of classical behaviour in cosmology. The key process in this respect is decoherence. In my talk, I describe two levels of this problem. First, there is the issue of the superposition of macroscopically different metrics. Second, there is the issue of the quantum fluctuations as predicted, for example, by inflationary cosmology. I discuss both cases and show how and to which extent classical behaviour emerges through decoherence. Observational aspects are also discussed. My emphasis is on conceptual problems rather than on technical issues.

Tim Langen

NON-EQUILIBRIUM DYNAMICS OF ONE-DIMENSIONAL BOSE GASES

Understanding non-equilibrium dynamics of quantum many-body systems is crucial for many fundamental and applied physics problems ranging from decoherence and equilibration to the development of future quantum technologies. I will give an overview of our recent results on the dynamics and thermalization of isolated quantum systems. In our experiment a one-dimensional Bose gas is trapped and split coherently into two parts using an atom chip. The time evolution following this quench leads to the establishment of a quasi-steady prethermalized state, which differs strongly from thermal equilibrium. Time-resolved measurements reveal that the thermal correlations of this prethermalized state first emerge locally and then spread through the system in a light-cone-like evolution. Moreover, the results show that the relaxed states of this nearly integrable quantum system can be described through a generalized Gibbs ensemble. Finally, I will report on the current progress in the understanding of thermalization beyond the transient prethermalized state and show how higher-order correlation functions can be employed for the tomography of quantum many-body states.

Emanuele Levi

QUANTUM CORRELATIONS AND NON-EQUILIBRIUM DYNAMICS OF RYDBERG GASES

Ensembles of cold atoms, ions and molecules offer a very promising route towards the controlled study of many-body quantum systems. In the case of Rydberg atoms in typical experimental setups one can achieve situations in which a single excitation blocks tens of hundreds of atoms, and leads to strong anti-correlation of excitations at small distances (the so called blockade effect).

However the nature of the correlations at longer distances is at present not fully understood.

A number of recent investigations suggest that the emerging states can be understood in terms of arrangements of hard objects, and as such behave essentially classically. To what extent there exist quantum correlations that go beyond the blockaded region is so far unclear.

In the first half of my talk I will address this questions in the case of a one dimensional Rydberg gas. In the second part I will consider a dissipative Rydberg gas, focusing on its universal non-equilibrium properties.

Throughout my talk I will connect our theoretical finding both qualitatively and quantitatively with recent experiments.

Wolfgang Rohringer

SCALE INVARIANCE IN A 1D BOSE GAS, ITS BREAKDOWN AND PHONON CREATION

For a certain class of Hamiltonians, the dynamics of cold atoms in time-dependent trapping potentials can be described in terms of scaling solutions, the existence of which is governed by a dynamical symmetry and scale invariance of the system. We present experimental results providing evidence for an approximate scale invariance in weakly interacting 1d Bose gases, governing the time evolution not only of the mean-field density profile, but the full spectrum of phononic excitations, in the presence of a collective breathing mode.

In addition, classical field simulations of the 1d expansion of a 1d Bose gas at finite temperature are presented. The results indicate that the breakdown of the approximate scale invariance leads to a sizeable increase of phonon occupation numbers in the scaling basis during the expansion even at moderate scale parameters. A scheme to measure this effect by extracting the atom number in the Penrose-Onsager mode is proposed.

Andrea Trombettoni

SUPPRESSION OF LANDAU INSTABILITY FOR SUPERSONIC SUPERFLUID FLOWS

For the 1D linear Schroedinger equation in presence of a square well/barrier potential the transmission coefficient can be exactly one for specific values of the incident momentum. In this talk I will consider the dynamical transmission properties for the Gross-Pitaveskii equation in presence of the quartic nonlinearity with the same potential and show that there are supersonic velocities fow which the Landau instability is dramatically reduced: these “Landau-free” momenta are shifted with respect to the corresponding resonant values for the linear case. The shift in momentum is seen to be positive (negative) for repulsive (attractive) interaction. We checked that the production of excitations at the supersonic Landau-free points is bounded in time, that the flow is stable both to small perturbations and for time larger than the typical experimental timescales of ultracold atoms experiments with 1D Bose condensates, and that the numerically obtained findings do not crucially depend on the ramping time of the well/barrier. A comparison with multiple-scale analysis for small nonlinearities is presented as well.

Bill Unruh

FALSE DECOHERENCE

Decoherence is usualy thought of as a system looking information about itself into the environmnet, and this is usually a one way process. However there are man situations in which coherence can be lost and regained again in a continous cycle. This is important for understanding the effect of the environmnet on a system, and in particular that while couplings can be present and large, and still not ultimately decohere the system. This is also important for "effective" quantum systems, which often cannot be described by a coherent low energy theory.

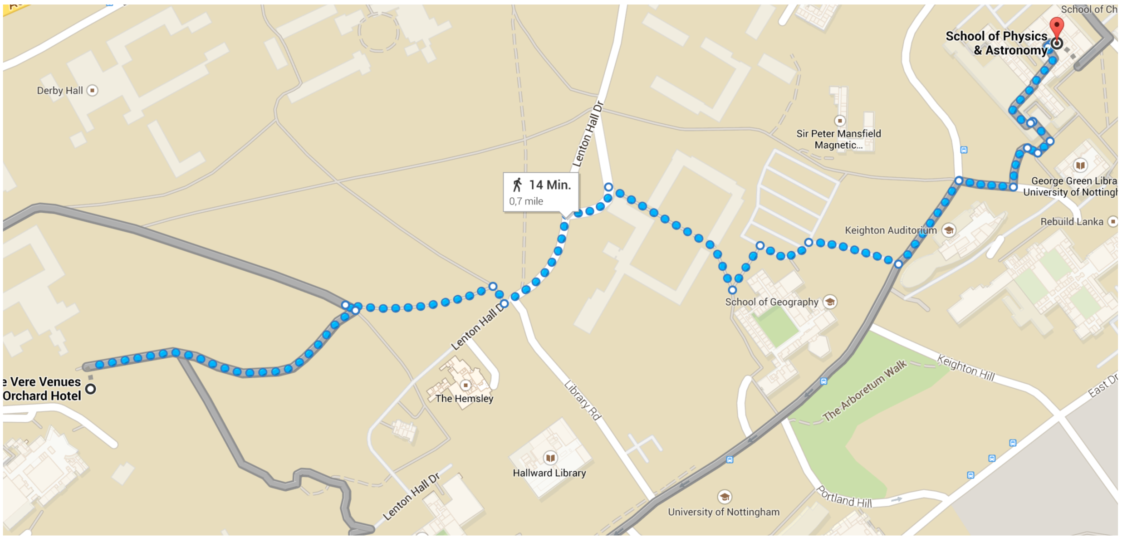
Chris Westbrook

CORRELATIONS AND ENTANGLEMENT IN BOSE EINSTEIN CONDENSATES

Our group in Palaiseau has been prefecting techniques for creating and analyzing correlated pairs of particles created through non-linear processes in BECs. We have been studying both correlated phonons via the dynamical Casimir effect as well as correlated atoms via a process analogous to four-wave mixing. I will discuss the experimental techniques and some of our latest results.

PROGRAM

All presentations will take place at the School of Physics & Astronomy, The University of Nottingham, Nottingham NG7 2RD in Room C27.



SUNDAY, 22 JUNE 2014

6-8 PM

Reception at the Orchard Hotel at the Bar (only for registered participants).

MONDAY, 23 JUNE 2014

9-10 AM

Ed Copeland (Inflation in light of Bicep2)

10-10.30 AM Coffee break (room B17)

10.30-11.30 AM

Claus Kiefer (Quantum-to-classical transition in cosmology)

11.30-12.30 AM

Dieter Jaksch (Tensor Network Theory and applications in non-equilibrium cold atom physics)

12.30-2 PM Lunch (room B17 - only for registered participants)

2-3 PM

Daniele Faccio (Analogue gravity in photon fluids - challenges and opportunities)

3-4 PM

Emanuele Levi (Quantum Correlations and non-equilibrium dynamics of Rydberg gases)

4.00-4.30 PM Coffee break (room B17)

4.30-5.30 PM

Andrea Trombettoni (Suppression of Landau Instability for Supersonic Superfluid Flows)

5.30-6.30 PM

Discussion (Chaired by Ted Jacobson)

7.15 PM SHUTTLE FOR **CONFERENCE DINNER** (only for registered participants): departure points for shuttle are the Orchards Hotel and the School of School of Physics & Astronomy.

TUESDAY, 24 JUNE 2014

9-10 AM

Bill Unruh (False Decoherence)

10-10.30 AM Coffee break (room B17)

10.30-11.30 AM

Chris Westbrook (Correlations and entanglement in Bose Einstein condensates)

11.30-12.30 AM

Piyush Jain (Damping and thermalization in a parametrically excited Bose gas)

12.30-2 PM Lunch (room B17 - only for registered participants)

2-3 PM

Wolfgang Rohringer (Scale invariance in a 1d Bose gas, its breakdown and phonon creation)

3-4 PM

Tim Langen (Non-equilibrium dynamics of one-dimensional Bose gases)

4.00-4.30 PM Coffee break (room B17)

4.30-5.30 PM

Clare Burrage (Detecting Dark Energy in the Laboratory)

5.30-6.30 PM

Discussion (Chaired by Ed Hinds)