UNIVERSIDAD DE CASTILLA-LA MANCHA

SOLIQUANTUM

Solitons and nonlinear phenomena in degenerate quantum gases

Escuela Politécnica,
Campus Universitario de Cuenca
Universidad de Castilla-La Mancha
Sep. 27-30, 2006

SOLIQUANTUM

Solitons and nonlinear phenomena
in degenerate quantum gases

Organized and sponsored by

Universidad de Castilla-La Mancha
Departamento de Matemáticas

Sponsored by

European Science Foundation
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Junta de Comunidades de
Castilla-La Mancha, Spain

Ministerio de Educación
y Ciencia, Spain

Contents

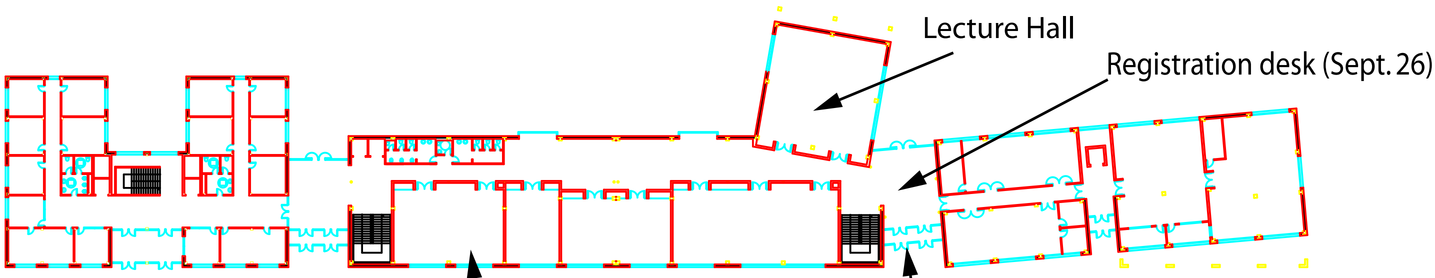
Maps

Map of Cuenca with indication of the places relevant to the conference SOLIQUANTUM. See also the map included with the turistic information.

Relevant addresses

- Conference site: Escuela Universitaria Politécnica de Cuenca. Address: Campus Universitario de Cuenca, Universidad de Castilla-La Mancha. A detailed map of the building is included in this book.
- Hotel Alfonso VIII. Address: Parque San Julián, 2. 16002 Cuenca. Phone: 969 212 512, web: `http://www.hotelalfonso-viii.com`.
- Hotel Leonor de Aquitania. Address: c/ San Pedro 60, 16001 Cuenca. Phone: 969 23 10 00, web: `http://www.hotelleonordeaquitania.com`.
- Parador de Cuenca. Address: Subida a San Pablo s/n. 16001 Cuenca. Phone: 969 232 320, `http://www.parador.es`.
- Restaurante Salón Latino (Lunches, Sept. 27-29). Address: Av. de los Alfares, s/n. 16002 Cuenca. Phone: 969 232 434.
- Restaurante Figón del Huecar (Dinner Sept. 27). Address: c/ Julián Romero, 6, Cuenca.
- Restaurante Recreo Peral (Dinner Sept. 28). Address: Carretera Cuenca-Tragacete, Km. 1. 16002 Cuenca, Phone: 969 224 643.
- Taxis: 969 23 33 43.

Conference site (Escuela Politécnica) maps



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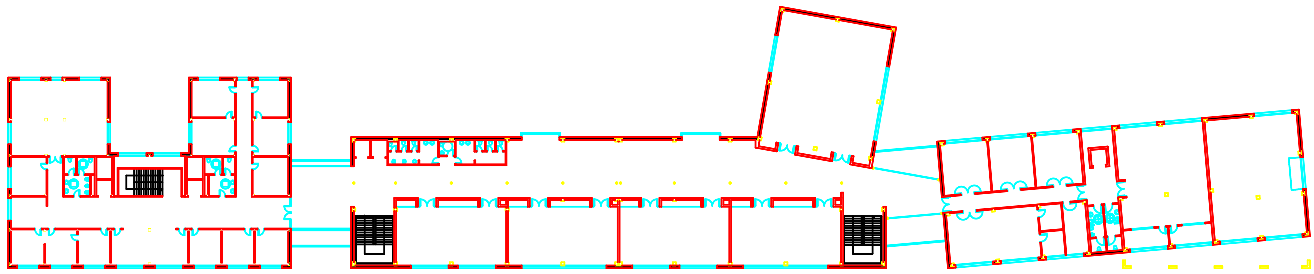

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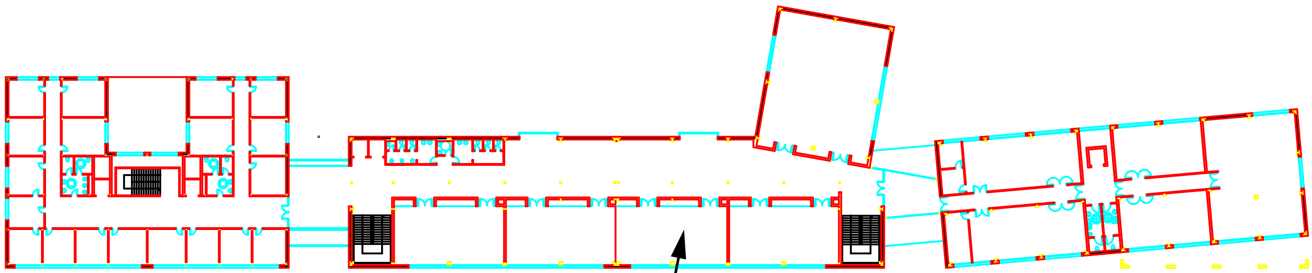

Level 2

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Transportation information

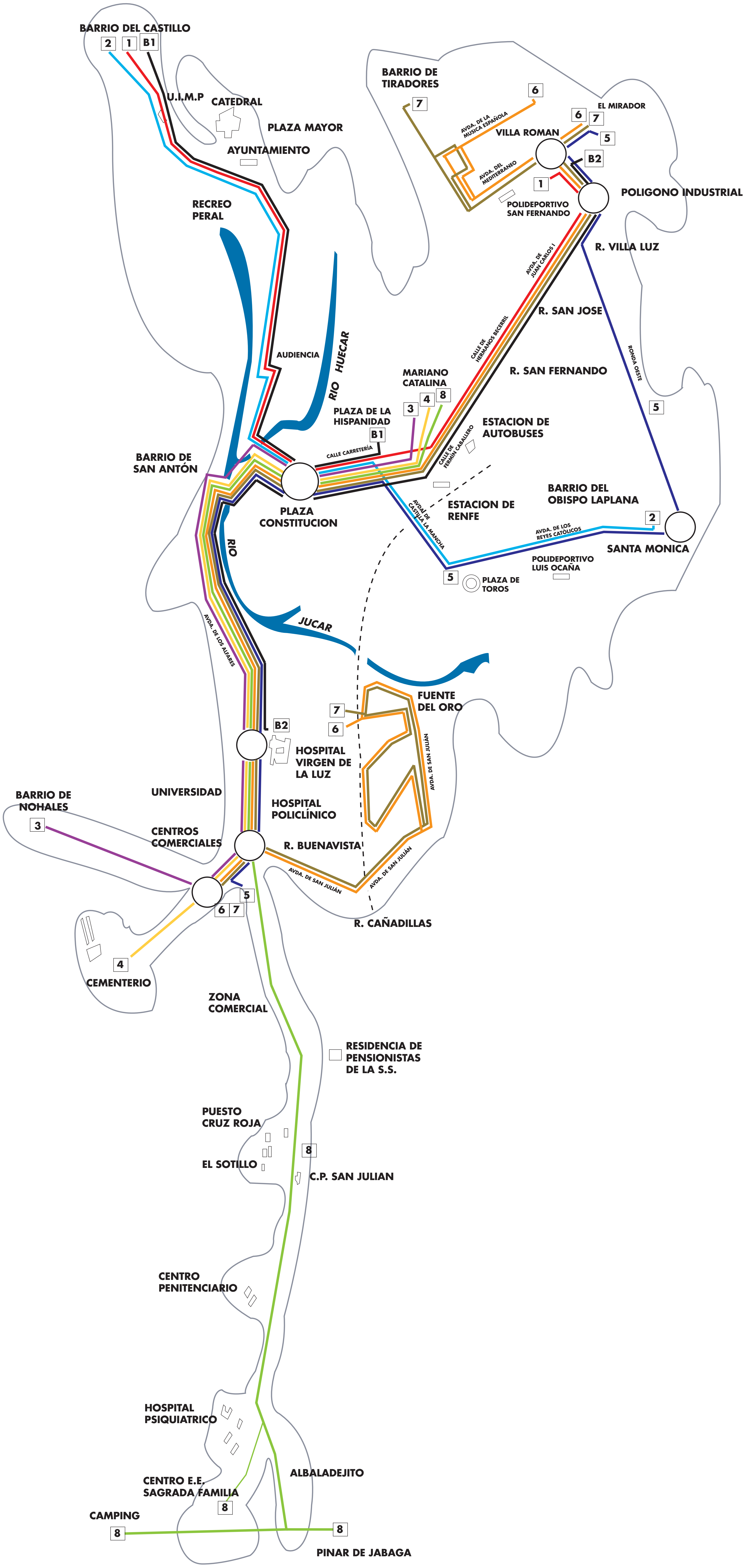
The conference takes place at the Politechnical School of the University of Castilla-La Mancha. The conference site is within walking distance from Hotel Alfonso VIII ($\sim$15-20 minutes)

Transportation services provided by the organization

- Every day a bus will depart at 9:00 from Hotel Leonor de Aquitania and then go to the university campus.
- Participants lodged at Parador can take this bus at an intermediate point to which they should go walking. More information will be available on the registration desk.
- Every day a bus will depart at 9:00 from Hotel Alfonso VIII to the university campus. The bus cannot stop in front of the hotel but there will be a member of the organization the first day who will explain you the exact departure place.
- On Sept. 27 buses will pick up participants after the last lecture and take them to the historic centre of the city for the guided tour. The tour will be walking and end at Restaurante Figón del Huecar for dinner. Buses will not be available to go back to the hotels but all of them are within walking distance from the restaurant (Leonor de Aquitania $\sim$ 5 minutes, Parador $\sim$10 minutes, Hotel Alfonso VIII $\sim$ 15 minutes. Members of the organization will guide you back to the hotels.
- Sept. 28 and 29: Buses will depart from the university to the hotels after the lectures at 18:30.
- Sept. 28. Buses will depart at 20:30 from Hotel Alfonso VIII and Hotel Leonor de Aquitania to Restaurante Recreo Peral (conference dinner).
- On Sept. 30 there will be a bus after lunch (14:30) from Escuela Politecnica to the railway station. This service provides a convenient connection with the train departing at 16:15 to Madrid.
- To reach the university by the city buses from Leonor de Aquitania take lines 1,2 or B1 to Plaza Constitucion and then either B2, 3, 4, 5, 6 or 7 to Universidad. You can ask at the hotel reception where is the bus stop.

Public transportation services

- To reach the university from Leonor de Aquitania take any of the following buses: 1,2 or B1 to Plaza Constitucion and then either B2, 3, 4, 5, 6 or 7 to Universidad.
- To reach the university from Hotel Alfonso VIII just walk to Plaza de la Constitución (see map) and then take any of the following buses: B2, 3, 4, 5, 6, 7.
- It is posible to pay the ticket in cash once in the bus.
- For more information on buses you can check the map included in the next page.


BARRIO DEL CASTILLO
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RECREO PERAL
AUDIENCIA
RIO HUECAR
BARRIO DE TIRADORES
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R. SAN JOSE
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AVDA. DE LOS ALFARES
FUENTE DEL ORO
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HOSPITAL PSIQUIATRICO
ALBALADEJITO
CENTRO E.E. SAGRADA FAMILIA
CAMPING
PINAR DE JABAGA

Conference Programme

SOLIQUANTUM Programme

	Wednesday, 27	Thursday, 28	Friday, 29	Saturday, 30
9:00	*Buses from Hotel Leonor de Aquitania and Hotel Alfonso VIII to the conference site*			
9:30-10:00	Formal inauguration & Conference info (1)	***Lattices*** Chairman: Salerno L. Fallani	***Managed interactions*** Chairman: Vekslerchik H. Michinel	***Bosons&Fermions*** Chairman: Oberthaler M. Salerno
10:00-10:30	***Solitons*** Chairman: Konotop S. Cornish	B. Malomed	P. Kevrekidis	V. V. Konotop
10:30-11:00	Coffee break			
11:00-11:30	C. S. Adams	K. Staliunas	Y. Kartashov	***Solitons in periodic systems*** Chairman:Brand M. Trippenbach
11:30-12:00	L. Khaykovich	V. Ahufinger	***Bosons&Fermions*** Chairman: Oberthaler H. T. C. Stoof	V. Brazhnyy
12:00-12:15	Discussion break			
12:15-12:45	L. Pitaevskii	***Vortices*** Chairman: Berloff A. Ferrando	S. K. Adhikari	L. Carr
12:45-13:05	V. Gerdjikov	S. Komikeas	M. Guilleumas	Y. Kivshar
13:05-15:15	Lunch			Lunch Buses depart at 14:30
15:15-15:45	***Vortices*** Chairman: Ferrando G. Volovik	***Solitons*** Chairman:Michinel A. Sanpera	***Long-range interactions*** Chairman: Brand J. Stühler	
15:45-16:15	N. Berloff	J. Brand	L. Santos	
16:15-16:35	B. Jackson	N. Pavloff	W. Krolikowski	
16:35-17:05	Coffee break			
17:05-17:35	***Solitons*** Chairman:Michinel V. Perez-Garcia	***Lattices*** Chairman: Konotop M. Lewenstein	***Coupled systems*** Chairman: Malomed M. Oberthaler	
17:35-17:55	G. Alfimov	V. Kuzmiak	V. M. Kaurov	
17:55-18:15	L. Salasnich	R. Franzosi	To be announced	
18:30-	Buses to the old city of Cuenca (guided tour). Dinner.	Buses to the hotels		
		20:30 Buses to the conference dinner (Recreo Peral).	Free (2)	

(1) The registration desk will be open on Tuesday Sept. 26 from 18:00 to 20:00 and during the conference.

(2) The organization does not cover this dinner. We suggest you to look through the touristic information to find many interesting places in the city.

Practical information

Presentations

When making your presentation please take into account the following recommendations:

- The time for your talk is indicated on the left pannel (typically 30 minutes for invited speakers and 20 minutes for junior and contributed presentations).
- Indicate the specific requirements for your talk (multimedia projector, overhead projector, blackboard, computer ...) on the registration desk as soon as possible in order to make the necessary arrangements.
- Introduce yourself if necessary to the session chairman before the session and fix with him the details of your presentation (i.e. which fraction of your time do you wish to leave for questions).

Computer access

- The building has a Wifi access to the university network and internet. To use it you must set up a Virtual Private Network (VPN) using an user and password to be provided at the registration desk.
- There is a computer room indicated in the map of the building which you can use during the conference (9:15-13:00 and 15:30-18:30). You can access to the computers using a generic user which will be given to you at the registration desk.

Registration desk

- The registration desk will be open on Tuesday 26 from 18:00 to 20:00 and during the conference (9:15-13:00 and 15:30-18:30).
- The assistant at the registration desk will give you the certificates of attendance, payment, etc starting from Sept. 28.
- For any question concerning Cuenca: restaurants, taxis, etc ... please ask the assistant at the Registration desk.

Abstracts

1 Bright matter wave soliton collisions in a harmonic potential.

Author: Charles S. Adams

Affiliation: Department of Physics, Durham University, United Kingdom

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WWW: `http:\\massey.dur.ac.uk\csa\`

We study collisions between bright matter wave solitons in a harmonic trap. For the quasi-one dimensional case we develop a particle model and show the motion can be choatic if there are more than two solitons undergoing collisions. In a three dimensional trap we characterize the regimes of elastic and inelastic collisions, and show that in the elastic regime mutli-soliton solutions remain stable for many seconds in agreement with recent experiments.

2 Fermionic collapse and soliton formation in a boson-fermion mixture.

Author: Sadhan K. Adhikari

Affiliation: Instituto de Física Teórica, Universidade Estadual Paulista, São Paulo, Brazil

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WWW: `http:\\www.ift.unesp.br\users\adhikari\index.html`

We use a time-dependent dynamical mean-field-hydrodynamic model to study the formation of fermionic bright solitons in a trapped degenerate boson-fermion mixture in a quasi-one-dimensional cigar-shaped geometry. Due to a strong Pauli-blocking repulsion among spin-polarized fermions at short distances there cannot be bright fermionic solitons in the case of repulsive boson-fermion interactions. However, we demonstrate that stable bright fermionic solitons can be formed for a sufficiently attractive boson-fermion interaction in a quasi-one-dimensional geometry. The Pauli repulsion also stops the collapse of a fermionic condensate. However, in a degenerate boson-fermion mixture for a sufficiently attractive boson-fermion interaction, there could be collapse in the fermionic component and we study the time evolution of this collapse in detail using the mean-field-hydrodynamic model.

3 Disordered ultracold Fermi-Bose mixtures in optical lattices.

Author: Veronica Ahufinger

Affiliation: Universitat Autònoma de Barcelona, Spain

email: Veronica.Ahufinger@uab.es

Collaborators: L. Sanchez-Palencia, A. Kantian, A. Sanpera, M. Lewenstein

We present a review of properties of ultracold atomic Fermi-Bose mixtures in inhomogeneous and random optical lattices. In the strong interacting limit and at very low temperatures, fermions form, together with bosons or bosonic holes, composite fermions. We derive the effective Hamiltonian describing the dynamics of the system and discuss its low temperature physics. Composite fermions behave as a spinless interacting Fermi gas, and in the presence of local disorder they interact via random couplings and feel effective random local potential. This opens a wide variety of possibilities of realizing various kinds of ultracold quantum disordered systems. In the weak disorder limit, results concerning the physics of composites, the realization of Fermi glass and the transition from Fermi liquid to Fermi glass will be presented while in the case of strong disorder, spin glasses will be discussed.

4 A way to classify localized modes for Gross-Pitaevskii equation.

Author: Georgy Alfimov

Affiliation: Moscow Institute of Electronic Engineering, Russia

email: galfimov@yahoo.com

Collaborators: D.Zezyulin

We show a way to describe localized modes for radial Gross-Pitaevskii equation with external trap potential. The basic tool for this approach is a simple numerical procedure which is a variation of shooting method. However, the advantages of this approach are as follows:

(a) it allows to give a complete picture of variety of localized modes, within specified range of parameters;

(b) it gives quite clear visual presentation of the branches of localized modes.

The points (a) and (b) allow to study easily the bifurcations of localized modes. The method is applied to parabolic, double-well and periodic trap potentials. Some new localized states are reported.

5 Existence, Stability and Explicit solutions to the 1D nonlinear Schrodinger equation with inhomogeneous nonlinearity.

Author: Juan Belmonte

Affiliation: Universidad de Castilla-La Mancha, Spain

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WWW: `http:\\matematicas.uclm.es\jbelmonte\`

Collaborators: Vadym Vekslerchik, Víctor M. Pérez García

We show the existence of solitary waves for the one- dimensional nonlinear Schrodinger equation (NLSE) with inhomogeneous nonlinearity, for negative energies, and we prove that for positive energies the only solution that fulfil the boundary conditions is the trivial solution. We give precise conditions for the orbital stability of these solitons or solitary waves and we obtain their basic properties. As well, we provide families of explicit solutions for particular case.

6 Vortices in inhomogeneous condensates.

Author: Natalia Berloff

Affiliation: University of Cambridge, United Kingdom

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WWW: `http:\\www.damtp.cam.ac.uk\user\ngb23\`

In the first part of my talk I will discuss how the Hamiltonian relationship between energy and momentum of a condensate can be used to study the motion of quantum vortices on inhomogeneous backgrounds and in the presence of surface boundaries. This method allows us to separate the effect of the surface from the effect of the density gradient and yields analytical expressions for the vortex velocity in trapped condensates.

In the second part of my talk I will elucidate the interaction of vortices with phase boundaries in two-component Bose-Einstain condensates. I will show that vortex rings can be used as an efficient machinery for inserting a controlled amount of atoms of one condensate into another.

7 Quantum reflection and dissipative motion of matter-wave solitons.

Author: Joachim Brand

Affiliation: Institute of Fundamental Sciences, Massey University, New Zealand

email: `J.Brand@massey.ac.nz`

WWW: `http:\\ ctcp.massey.ac.nz\`

Localization of waves in space and particle-like properties under collisions constitute the fascinating phenomena that led to the notion of a soliton. How much of the classical particle-like properties of solitons remain for the matter-wave solitons that can be studied with Bose-Einstein condensates? In this talk I will discuss how bright matter-wave solitons can acquire dissipative and non-classical properties. Friction and diffusion of solitons are predicted under the influence of a thermal background as the consequence of microscopic scattering events. We study the effect of three-dimensional confinement on the scattering of thermal atoms on the soliton [1].

Non-classical behaviour of solitons manifests itself in the quantum reflection of the soliton from an attractive potential [2]. The non-classical reflection occurs at small velocities and a pronounced switching to almost perfect transmission above a critical velocity is found, caused by nonlinear mean-field interactions. Full numerical results from the nonlinear Schroedinger equation are complimented by a two-mode variational calculation to explain the predicted effect, which can be used for velocity filtering of solitons. The experimental realization with laser-induced potentials or two-component Bose-Einstein condensates is suggested.

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[1] . Sinha, A. Yu. Cherny, D. Kovrizhin, and J. Brand; Friction and diffusion of matter-wave bright solitons. Phys. Rev. Lett. 96, 030406(2006)

[2] h. Lee and J. Brand; Enhanced quantum reflection of matter-wave solitons. Europhys. Lett. 73, 321 (2006).

8 Defect modes of a Bose-Einstein condensate in an optical lattice with a localized impurity.

Author: Valeriy Brazhnyy

Affiliation: Departamento de Fisica, Universidade de Lisboa, Portugal

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WWW: `http:\\cftc.cii.fc.ul.pt\~cftcweb\MEMBERS\VB.en.html`

Collaborators: V. V. Konotop, V. M. Pérez-García

We study defect modes of a Bose-Einstein condensate in an optical lattice with a localized defect within the framework of the one-dimensional Gross- Pitaevskii equation. It is shown that for a significant range of parameters the defect modes can be accurately described by an expansion over Wannier functions, whose envelope is governed by the coupled nonlinear Schrödinger equations with a δ impurity. The stability of the defect modes is verified by direct numerical simulations of the underlying Gross-Pitaevskii equation with a periodic and defect potentials. We also discuss possibilities of driving defect modes through the lattice and suggest ideas for their experimental generation.

9 Nonlinear band structure of Bose-Einstein condensates.

Author: Lincoln Carr

Affiliation: Physics Department, Colorado School of Mines, USA

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Starting from the full solution of the stationary nonlinear Schrodinger equation in the presence of an impurity, i.e., a delta distribution, we build up a full picture on nonlinear band theory for a Kronig-Penney potential. This has the advantage of being a completely analytically tractable lattice theory. The appearance of swallowtails in the bands is examined and interpreted in terms of the condensate superfluid properties. The nonlinear stability properties of the Bloch states are described and the stable regions of the bands and swallowtails are mapped out. A connection between swallowtails and period-doubled solutions is also described.

10 Transport of coherent interacting matter-waves in a 1D random potential.

Author: David Clement

Affiliation: Laboratoire Charles Fabry, Institut d'Optique, France

email: `david.clement@iota.u-psud.fr`

WWW: `http:\\atomoptic.iota.u-psud.fr`

Disorder in quantum systems has been the subject of intense theoretical and experimental activites during the past decades, predicting the most famous and spectacular phenomenon of Anderson localization. In interacting systems such as cold atoms, the situation is even more tricky and rich as the result of non-trivial interplays between kinetic energy, interactions and disorder. We are interested in these interplays and its consequences on transport of a Bose-Einstein condensate in a 1D random potential created by a speckle pattern. We observed a suppression of transport properties of an expanding coherent matter-wave of interacting particles (PRL 95, 170409(2005)). We have studied recently in details the effects of the interactions on the expansion of a BEC to get a complete picture of the phenomena underlying the absence of diffusion (paper in preparation). In particular we argue that a classical picture is valid for the trapping in a random potential due to interactions.

11 Formation of bright matter-wave solitons during the collapse of attractive Bose-Einstein condensates.

Author: Simon Cornish

Affiliation: Durham University, United Kingdom

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WWW: http:\\massey.dur.ac.uk\slc\

Collaborators: S.T. Thompson, C.E. Wieman

We observe bright matter-wave solitons form during the collapse of ^{85}Rb condensates in a three-dimensional (3D) magnetic trap [1].

The collapse is induced by using a Feshbach resonance to suddenly switch the atomic interactions from repulsive to attractive [2].

Our previous observations of the collapse process [3] revealed that remnant condensates containing several times the critical number of atoms for the onset of instability survive the collapse. It was not understood why such condensates did not undergo further collapse until the number of atoms remaining was below the critical number. In the work presented here, we explain this result by showing that the remnant condensate forms a highly robust configuration of 3D solitons, such that each soliton satisfies the condition for stability. The solitons are observed to oscillate along the (weaker) axial direction of the trap, colliding repeatedly in the trap centre. The stability of this motion out to long observation times indicates that neighboring solitons have a relative phase that ensures that they interact repulsively even though the atomic interactions are attractive [4].

[1] S. L. Cornish, S. T. Thompson and C. E. Wieman, Phys. Rev. Lett. 96, 170401 (2006).

[2] S. L. Cornish, N. R. Claussen, J. L. Roberts, E. A. Cornell and C. E. Wieman, Phys. Rev. Lett. 85, 1795 (2000).

[3] E. A. Donley, N. R. Claussen, S. L. Cornish, J. L. Roberts, E. A. Cornell and C. E. Wieman, Nature 412, 295 (2001).

[4] N. G. Parker, A. M. Martin, S. L. Cornish, and C. S. Adams, cond-mat\0603059.

12 Existence of discrete solitons in rotating optical lattices.

Author: Jesús Cuevas Maraver

Affiliation: Universidad de Sevilla, Spain

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WWW: `http:\\www.personal.us.es\jcuevas`

Collaborators: Boris Malomed and Panayotis Kevrekidis

In this talk we will show some preliminary results about the existence of fundamental solitons in a rotating optical lattices. We will consider the limit case of a very strong lattice, which is described by a modified 2D Discrete Nonlinear Schrödinger Equation. The results are not only interesting for its application to Bose-Einstein Condensates or nonlinear optics but also for a better understanding of the properties of nonlinear nonhomogeneous lattices.

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[1] J. Cuevas, J.F.R. Archilla, F. Palmero and F.R. Romero: "Numerical study of two-dimensional disordered lattices with cubic soft anharmonicity". J. Phys. A 34 (2001) L221

[2] R. Bhat, M.J. Holland and L.D. Carr: "Bose-Einstein Condensates in rotating lattices". PRL 96 (2006) 060405

[3] G. Kopidakis and S. Aubry: "Intraband discrete breathers in disordered nonlinear systems: I. Delocalization". Physica D 130 (1999) 155. "Intraband discrete breathers in disordered nonlinear systems: II. Localization". Physica D 139 (2000) 247

[4] T. Pertsch, U. Peschel nad F. Lederer: "Discrete solitons in inhomogeneous waveguide arrays". Chaos 13 (2003) 744

13 Insulating phases of ultracold bosons in a disordered optical lattice.

Author: Leonardo Fallani

Affiliation: LENS European Laboratory for Non-linear Spectroscopy and Dipartimento di Fisica, Universita di Firenze, Italy.

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Collaborators: J. E. Lye, V. Guarrera, C. Fort, M. Inguscio

Ultracold atoms in optical lattices not only constitute an artificial system where it is possible to recreate the physics of an ideal solid state. They are revealing as powerful tools to study the physics of complex systems, thanks to the possibility to accurately control the kind and amount of disorder. We have experimentally studied a system of bosonic ^{87}Rb atoms in a 3D optical lattice, where disorder is added at the length scale of the single lattice sites by using an auxiliary optical lattice at a non-commensurate wavelength. Increasing the amount of disorder, we observe the transition from a Mott insulating state, featuring an energy gap and well resolved resonances, towards a novel gapless insulating phase, that can be identified with a Bose-Glass. We discuss the experimental results and possible perspectives of this system for the investigation of different disordered-related phenomena.

14 Vorticity control using discrete-symmetry potentials.

Author: Albert Ferrando

Affiliation: Interdisciplinary Modeling Group, InterTech. Departament d'Òptica, Universitat de València, Spain

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WWW: http:\\www.intertech.upv.es

Collaborators: Víctor M. Pérez-García and Miguel A. García-March

Vortices are a physical phenomenon common to all complex waves. In wave mechanics a vortex is a screw phase dislocation, or defect [1], where the amplitude of the field vanishes. The phase around this singularity presents an integer number of windings, ℓ. In full rotational invariant systems, this number corresponds to the angular momentum of the solution with respect to the singularity. In these systems, besides, this quantity is a conserved quantity and determines the interactions between vortices in a very similar way to electrostatic charges. For this reason, ℓ is also called the *topological charge* of the vortex.

Angular momentum is conserved in a quantum system with $O(2)$ rotational symmetry. If we consider a state with well-defined angular momentum $\ell \in \mathbb{Z}$, i.e., an eigenfunction of the angular momentum operator at a given time t_0, its evolution will preserve the value of ℓ. In a system possessing a discrete point-symmetry (described by the C_n and C_{nv} groups) the angular momentum is no longer conserved. However, in this case one can define another quantity $m \in \mathbb{Z}$, the Bloch or angular pseudo-momentum, which is conserved under time evolution [2]. The angular pseudo-momentum m plays then the role of ℓ in a system with discrete rotational symmetry. From the group theory point of view, the angular and angular pseudo momenta ℓ and m are also the indices of the 2D irreducible representations of O(2) and C_n, respectively [3, 4, 5]. Unlike ℓ, the values of m are limited by the order of the point-symmetry group C_n. Consequently, the appearance of this upper bound for the angular pseudo-momentum m opens the interesting question of determining the behavior of solutions propagating in an O(2) rotational invariant medium with well-defined angular momentum l after switching on a potential with discrete symmetry of finite order — especially in the case when l exceeds the upper bound for m.

In this contribution we will explore the application of group theory to control the topological charge of vortices in Bose-Einstein condensates by using external potentials with discrete rotational symmetry. To do so we propose a very simple setup based on a non-periodic potential with discrete rotational symmetry which will allow us to perform many operations with the vortex charges depending on the initial charge and the potential symmetry order. While the vortex transmutation phenomenon has been previously explored in potentials with broken symmetries [6] and in the context of photonic lattices [7, 8], other operations to be proposed here have not been studied before. Our proposal is simpler to implement than the 2D lattice type potentials proposed in the framework of photonic lattices and is easier to reconfigure. We will also show how starting from multiply charged vortices such as the ones which can be generated in atom chips by phase-imprinting methods one can generate different types of vortices by choosing an appropriate control potential.

[1] J. F. Nye, M. V. Berry, Proc. R. Soc. London A **336**, 165-190 (1974).

[2] A. Ferrando, Phys. Rev. E **72**, 036612 (2005).

[3] A. Ferrando, M. Zacarés, P. Fernández de Córdoba, J. A. Monsoriu, and P. Andrés, Opt. Express 13, 1072 (2005).

[4] M. Hamermesh, Group Theory and its Application to Physical Problems, Addison-Wesley Series in Physics (Addison-Wesley, Reading, MA, 1964), 1st ed.

[5] A. Ferrando, M. Zacarés, and M. A. García-March, Phys. Rev. Lett. 95, 043901 (2005).

[6] J. J. García-Ripoll, G. Molina-Terriza, V. M. Pérez-García, and Ll. Torner, Phys. Rev. Lett. **87**, 140403 (2001).

[7] A. Ferrando, M. Zacarés, and M. A. García-March, J. A. Monsoriu, and P. Férnandez de Córdoba, Phys. Rev. Lett. 95, 123901 (2005).

[8] Y. V. Kartashov, A. Ferrando, A.A. Egorov, and Ll. Torner, Phys. Rev. Lett. **95**, 123902 (2005).

15 Probing Bose-Einstein Condensates via Dissipative Cooling.

Author: Roberto Franzosi

Affiliation: Dept. of Physics and CNR-INFM, University of Florence, Italy

email: `franzosi@fi.infn.it`

We study a model of a 1D optical lattice equipped with dissipative boundary conditions. We show how many characteristic dynamical regimes can be triggered in the system, and how measurements on the emitted atoms can be exploited for determining the presence and nature of the dynamics of Bose-Einstein condensates inside the lattice.

16 Thermally induced instability of a doubly quantized vortex in a Bose-Einstein condensate.

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We study the instability of a doubly quantized vortex topologically imprinted on ^{23}Na condensate, as reported in recent experiment [Phys. Rev. Lett. **93**, 160406 (2004)]. We have performed numerical simulations using three-dimensional Gross-Pitaevskii equation with classical thermal noise. Splitting of a doubly quantized vortex turns out to be a process that is very sensitive to the presence of thermal atoms. We observe that even very small thermal fluctuations, corresponding to 10 to 15% of thermal atoms, cause the decay of doubly quantized vortex into two singly quantized vortices in tens of milliseconds. As in the experiment, the lifetime of doubly quantized vortex is a monotonic function of the interaction strength.

17 On soliton interactions and stability: effects of external potentials.

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The dynamics of a train of matter - wave solitons in a one-dimensional BEC confined to a parabolic trap and optical lattice, as well as tilted periodic potentials. We demonstrate that there exist critical values of the strength of the linear potential for which one or more localized states can be extracted from a soliton train. The linear stability of solitons in media with cubic and quadratic nonlinearities has been investigated. A generalization of the complex Toda chain model describing the N-soliton interactions in the adiabatic approximations is obtained using the variational approach.

18 Mean-field instability in attractive Bose-Fermi mixtures.

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We investigate within the mean-field framework the stability diagram of a confined mixture of ^{87}Rb bosons and spin-polarized ^{40}K fermions in the quantal degeneracy regime with attractive interspecies interaction. We study the stability of the attractive mixture in an elongated trap and discuss the effect of the inclusion of the p-wave interaction between bosons and fermions near collapse in the mean-field approximation. The onset of instability of the mixture occurs for a lower number of fermions when the p-wave interaction is considered.

19 Hysteresis and finite temperature solitons in Bose-Einstein condensates.

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Collaborators: C.F. Barenghi, and N.P. Proukakis

We first simulate the formation of vortices in a dilute Bose-Einstein condensate confined in a rotating anisotropic trap. We find that the number of vortices and angular momentum attained by the condensate depends upon the rotation history of the trap and on the number of vortices present in the condensate initially. A simplified model based on hydrodynamic equations is developed and used to explain these results.

The simulations are performed for zero temperature, and a central question relates to whether these types of phenomena persist at finite temperatures. As part of the development of a model to address this question we have considered the dynamics of a dark soliton in an elongated harmonically trapped Bose-Einstein condensate, which at zero temperature oscillates along the axial direction due to the inhomogeneous background density. For finite temperatures we use coupled Gross-Pitaevskii and many-body simulations, which includes the coupling between the condensate and thermal components. We find that the oscillation persists at finite T, but steadily increases in amplitude due to the decay of the soliton. We find that this decay process is rapid even at low temperatures.

20 Bright solitons in 3D Bose-Fermi mixtures.

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We consider the formation of bright solitons in a mixture of Bose and Fermi degenerate gases confined in a three-dimensional elongated harmonic trap. The Bose and Fermi atoms are assumed to effectively attract each other whereas bosonic atoms repel each other. Strong enough attraction between bosonic and fermionic components can change the character of the interaction within the bosonic cloud from repulsive to attractive making thus possible the generation of bright solitons in the mixture. On the other hand, such structures might be in danger due to the collapse phenomenon existing in attractive gases. We show, however, that under some conditions (defined by the strength of the Bose-Fermi components attraction) the structures which neither spread nor collapse can be generated. For elongated enough traps the formation of solitons is possible even at the "natural" value of the mutual Bose-Fermi (^{87}Rb-^{40}K in our case) scattering length.

21 Surface matter-wave solitons.

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Collaborators: Fangwei Ye and Lluis Torner

We predict the existence and study the basic properties of strongly asymmetric matter wave solitons that form at the interface produced by regions with different inter-atomic interaction strengths in pancake Bose-Einstein condensates. We address several types of surface solitons featuring topologically complex structures, including vortex and dipole-mode solitons. We found that the soliton become significantly asymmetric for high soliton norms. Yet, we reveal that even such strongly asymmetric dipole and vortex solitons can be dynamically stable over wide regions of their existence domains.

22 Atomic Josephson Vortex.

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Two parallel BEC waveguides coupled by tunneling (long quasi-1D Bose Josephson Junction), besides the usual dark soliton (DS), can support another soliton with circulating supercurrent – atomic Josephson vortex (JV). Exact solution for the stationary JV is found. JV and DS can be reversibly interconverted into each other by tuning the Josephson coupling strength above and below a particular critical value. Due to a specific Berry phase structure of the JV, it can be controllably accelerated by changing the relative chemical potential of the waveguides. Acceleration of the vortex up to a certain threshold speed, depending on the Josephson coupling, results in the phase slip causing switching of the vorticity. A JV can be created by the phase imprinting technique and can be identified by a specific tangential feature in the interference absorptive pattern. We propose that the JV can be utilized for coherent controlled transfer of BEC and as a mobile qubit.

23 Solitary Wave Dynamics In The Presence of Spatial or Temporal Periodicity: Some Case Examples From BECs and Nonlinear Optics.

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In this talk, we will present a variety of recent developments in the theory of BECs and of photorefractive crystals, motivated by an overarching theme of spatial or temporal periodicity/discreteness. This will be accomplished through several vignettes including but not limited to:

a) 2-well, 3-well and infinite well settings and their instabilities;
b) discrete solitons and vortices in square and radial lattices;
c) temporal periodicity and layered media;
d) lattices of components (multi-component systems) and their dynamics.

One of the key features of the talk will be that for each of the above directions, the analytical and numerical results discussed will be compared at least qualitatively and whenever possible also quantitatively with experimental results. Interesting directions for future work will also be delineated.

24 Towards experimental realization of matter-wave soliton collisions: signature of deviation from one dimensionality.

Author: Lev Khaykovich

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We report progress towards experimental realization of collisions of bright matter-wave solitons formed from a lithium Bose-Einstein condensate (BEC). We also present our theoretical study of how the residual three dimensionality affects stationary properties and collisional dynamics of solitons. For two colliding imperfectly-1D solitons we show a critical velocity, V_c, below which merger of identical in-phase solitons is observed. Dependence of V_c on the strength of the transverse confinement and number of atoms in the solitons is predicted by means of the perturbation theory and investigated in direct simulations. The simulations also demonstrate symmetry breaking in collisions of identical solitons with a nonzero phase difference. This effect is qualitatively explained by means of an analytical approximation.

25 Matter-wave gap solitons and vortices in optical lattices.

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We will overview our theoretical results on matter-wave gap solitons and gap vortices in one-, two- and three-dimensional optical lattices. In particular, we will discuss the process of the gap-soliton generation and also demonstrate that the recently observed self-trapping effect in optical lattices may be attributed to the existence of novel types of localized gap states resembling truncated nonlinear Floquet-Bloch modes. We will also discuss how the lattice symmetry changes the stability of gap solitons and vortex lattices.

26 Single vortex states and virial theorems in a confined Bose-Einstein condensate.

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We derive a class of virial theorems which provide stringent tests of both analytical and numerical calculations of vortex states in a confined Bose-Einstein condensate. In the special case of harmonic confinement we arrive at the surprising conclusion that the linear moments of the particle density, as well as the linear momentum, must vanish even in the presence of off-center vortices which lack axial or reflection symmetry.

Two types of non-axisymmetric vortices have been observed to precess around the center of a condensate and they are refered to as the S-vortex and the U-vortex. We study numerically (Gross-Pitaevskii equation) and theoretically a single vortex in spherical and elongated condensates as a function of the interaction strength. For given angular momentum the S-vortex has a smaller precession frequency and a higher energy than the U-vortex in a rotating elongated condensate. We show that the S-vortex is related to the solitonic vortex and also to the dark soliton which are nonlinear excitations in the nonrotating system.

27 Localized modes and gap solitons in arrays of boson-fermion mixtures.

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Collaborators: Yu. V. Bludov

It is shown that the mean-field description of a boson-fermion mixture with a dominating fermionic component, loaded in a one-dimensional optical lattice, is reduced to the nonlinear Schrodinger equation with a periodic potential and periodic nonlinearity. In such a system there exist localized modes having peculiar properties. In particular, for some regions of parameters there exists a lower bound for a number of atoms necessary for creation of a mode, while for other domains small amplitude gap solitons are not available in vicinity of either of the gap edges. We found that the lowest branch of the symmetric solution may either exist only for a restricted range of energies in a gap or does not exist, unlike in pure bosonic condensates. The simplest bifurcations of the modes are shown and stability of the modes is verified numerically. We also discuss modulational instability and gap solitons in boson-fermion mixtures in a quasi-one-dimensional lattice, as well as possibilities of their manipulation by means of external factors.

28 Wave localization in nonlocal nonlinear media.

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Solitons have been typically considered in the context of the so called local nonlinear media. In such media nonlinear response induced by an optical beam in a particular point depends solely on the beam intensity in this very point. However, in many optical systems the nonlinear response of the medium is actually a spatially nonlocal function of wave intensity. This occurs, for instance, in systems exhibiting a long-range interaction of constituent molecules or particles such as in nematic liquid crystals or dipolar Bose Einstein condensates. Nonlocality is thus a feature of a large number of nonlinear systems leading to novel phenomena of a generic nature. In this work I discuss such effects as nonlocality-mediated modulational instability, collapse arrest of multidimensional beams in self-focusing media. I will also show that nonlocal media may support variety of stationary localized structures - spatial solitons. They include, for instance, multi-hump and ring vortex solitons. I will also demonstrate that the stability of these structures critically depends on the spatial profile of the nonlocal response function.

29 Nature of the intrinsic relation between Bloch-band tunneling and modulational instability.

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Collaborators: V.A. Brazhnyi, V.V. Konotop

We have demonstrated on an example of Bose-Einstein condensates embedded in a two-dimensional optical lattice that modulational instability and inter-band nonlinear tunneling are intrinsically related phenomena in nonlinear periodic systems. By employing direct numerical simulations we found that the tunneling may lead to the attenuation or enhancement of instability, the latter of which, in turn gives rise to asymmetric nonlinear tunneling. Specifically, we found that the atoms initially loaded in a stable state develop instability due to the inter-band exchange, while the resonant tunneling attenuates instability when atoms are initially loaded in an unstable state. The interaction between the instability and the tunneling strongly depends on the band structure, in particular in the case of the resonant tunneling when the lattice with negligible gap satisfies matching conditions for the four-wave interactions. The symmetry of the coherent structures emerging from the instability reflect the symmetry of both stable and unstable states between the tunneling occurs and appears to be one of the key factors in the superfluid-insulator transition.

30 Spintomics, or how can one play with large spins.

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In my lecture I will discuss several new ideas of employing large atomic spins. First of all, I will discuss ultracold atoms with spin $F = 1, 3/2, 2, ...$ in optical lattices, where the spin degree of freedom allows to create various exotic quantum phases. Second, we will discuss methods of detection of these phase by employing atom-light interface and quantum Faraday effect, in similar manner as it is done in experiments of E. Polzik group. The detection scheme allows to measure quantum fluctuations of the global atomic spin. Finally, I will discuss methods of reading out infromations about entaglement in the system by looking at the global spin fluctuations. This method is in particular applied to a mesoscopic system of 8 trapped ions in a so called $|W>$ state, recently observed by the Rainer's Blatt group.

31 Matter-wave solitons in parallel-coupled traps equipped with optical lattices.

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Collaborators: Arthur Gubeskys

We study spontaneous symmetry breaking of solitons in linearly coupled one-dimensional Bose-Einstein condensates (BECs) trapped in optical lattices (OLs). The coupled equations give rise to a complex structure of spectral bandgaps. Each ordinary gap of the single-core OL either partially closes or splits into several gaps. The symmetry-breaking problem for solitons is considered for attractive and repulsive condensates separately (attraction/attraction, A/A, and repulsion-repulsion, R/R, models). In both models asymmetric solitons are found for sufficiently small strength of the linear coupling. In the A/A model, the branch of symmetric soliton solutions bifurcates into asymmetric solutions. On the contrary, in the R/R case, asymmetric solitons appear as a result of a symmetry-breaking bifurcation of the anti-symmetric solitons. Solitons stability is investigated in direct simulations, and by computation of eigenvalues for small perturbation modes. In the A/A model, symmetric solitons destabilize beyond the bifurcation point, while the newly born asymmetric solitons are stable, anti-symmetric solitons being always unstable. In the R/R model we observe bi-stability: while symmetric solitons are always stable, their anti-symmetric counterparts are stable before the bifurcation. Beyond the bifurcation, anti-symmetric soliton destabilize, and stable asymmetric solitons appear. Thus, the R/R model always supports two stable species of solitons: symmetric and either anti-symmetric or asymmetric ones. Soliton solutions are also found in a mixed model of the A/R type, with the attractive interaction in one component, and repulsive interaction in the other.

32 Bright Matter-Wave Soliton Collisions in a Harmonic Trap: Regular and Chaotic Dynamics.

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Collisions between bright solitary waves in the 1D Gross-Pitaevskii equation with a harmonic potential, which models a trapped atomic Bose-Einstein condensate, are investigated theoretically. A particle analogy for the solitary waves is formulated, which is shown to be integrable for a two-particle system. The extension to three particles is shown to support chaotic regimes. Good agreement is found between the particle model and simulations of the full wave dynamics, suggesting that the dynamics can be described in terms of solitons both in regular and chaotic regimes, thus presenting a paradigm for chaos in wave-mechanics.

33 Partially incoherent gap solitons in Bose-Einstein condensates.

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Collaborators: Boris A. Malomed and Y. B. Band.

We construct incoherent matter-wave solitons in a repulsive degenerate Bose gas trapped in an optical lattice (OL), i.e., gap solitons, and investigate their stability, within the Hartree-Fock-Bogoliubov setting. The gap solitons are composed of a coherent condensate, and normal and anomalous densities of the incoherent vapor co-trapped with the condensate. Both intragap and intergap solitons are constructed, with chemical potentials of the components falling in one or different bandgaps in the OL-induced spectrum. Families of intragap solitons are completely stable(both in direct simulations, and in terms of eigenvalues of perturbation modes), while the intergap family shows a very weak instability.

34 Emission and Acceleration of Bose-Einstein Solitons.

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Collaborators: M. I. Rodas-Verde, A. V. Carpentier and V. M. Pérez-García

We have analyzed several aspects concerning the emission and control of matter-wave solitons which are obtained by spatial modulation of the scattering length in the vicinity of a Bose-Einstein Condensate. We describe two different devices that can be implemented in the frame of current experiments: an atomic soliton laser and a ring accelerator.

The atomic soliton laser is based on the process called soliton emission, that takes place when a dipole trap is connected to a region with attractive nonlinear atom-aton interactions. If the energy of these forces overcomes the potential barrier of the well, matter-wave bursts composed by several soliton packets are emitted.

Atomic solitons can be stored in ring reservoirs. By acting on them with modulated optical potentials it is possible to accelerate the atomic bemas without spreading of the cloud. A robust control of the motion can be obtained by means of optical AM/FM lattices.

35 Two weakly coupled condensates - dynamics and finite temperature effects.

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The realization of two weakly linked degenerate Bose gases - a bosonic Josephson junction - allows for the direct observation of the tunneling dynamics and its modification due to the interactions between the particles. It also opens up the way to study the influence of residual thermal excitations in these mesoscopic quantum gases.

Here we report on the observation of the dynamical modes of Josephson oscillations and macroscopic self-trapping in a single bosonic Josephson junction. We also report on the experimental investigation of fluctuations of the relative phase between two coupled Bose-Einstein condensates arising from the interaction with the thermal environment. The comparison with a classical model as well as with the Bose Hubbard model reveals quantitative agreement between theory and experiment. Therefore we can apply the measurements of the phase fluctuations to deduce the temperature in a regime where standard methods fail and thus realize a primary thermometer for ultracold degenerate bosonic gases far below the critical temperature. The talk will be concluded with the presentation of preliminary data on the generation of atomic dark soliton trains utilizing a Bose gas in a double well potential.

36 Non linear transport in disordered Bose-Einstein condensates.

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We study nonlinear transport in quasi 1D BEC systems. We consider in particular two nonlinear phenomena: solitonic transport and multistability, and discuss the issue of Anderson localisation in the system.

37 Dissipative solitons in Bose-Einstein condensates: Solitons that cannot be trapped.

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Collaborators: Adrian Alexandrescu and Rosa Pardo

We show how long-lived self-localized matter waves can exist in Bose-Einstein condensates with a nonlinear dissipative mechanism. The ingredients leading to such structures are a spatial phase generating a flux of atoms towards the condensate center and the dissipative mechanism provided by the inelastic three-body collisions in atomic Bose-Einstein condensates. The outcome is an striking example of *nonlinear structure supported by dissipation*.

We also study rigorously how these dissipative solitons cannot survive under the effect of trapping potentials both of rigid wall type or asymptotically increasing ones. This provides an curious example of a soliton which cannot be trapped and only survives to the action of a weak potential. We discuss the physical implications of the phenomenon.

38 Solitons as elementary excitations.

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Two challenging 3D and 2D problems, where considering solitons as quantum elementary excitations is useful, are discussed.

The stability of the Jones-Roberts (JR) solitary waves in 3D Bose-Einstein condensates with respect to quantum decay into several phonons is investigated. The conservation laws permits such a decay for the upper branch of JP dispersion curve and for the part of lower branch which lies above the sound line. The minimal number of phonons in which an excitation with given energy and momentum can decay is estimated. This number depends of the gas parameter of the fluid.

The small oscillations of solitons in 2D Bose-Einstein condensates are investigated by solving the Kadomtsev-Petviashvili equation which is valid when the velocity of the soliton approaches the speed of sound.

The soliton is stable and its lowest excited states obey the dispersion law which is quite similar to the one of the stable branch of excitations of a 1D gray soliton in a 2D condensate. The role of these states in thermodynamics is discussed. It occurs that they can give an anomalous contribution in the specific heat.

39 Thermodynamics of Solitonic Matter Waves in a Toroidal Trap.

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We study a Bose-Einstein condensate with negative scattering length confined in a toroidal trapping potential. We investigate the effect of temperature on the transition from the uniform to the localized state and predict the phase diagram of the system. We calculate the temperature of the Bose-Einstein condensation for a sample of alkali-metal atoms in a quasi one-dimensional ring, and the critical interatomic strength of the quantum phase transition to the symmetry-breaking state, where a bright-soliton condensate and a localized thermal cloud coexist.

40 Bose-Fermi mixtures in optical lattices.

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We discuss properties of ultracold atomic Bose-Fermi mixtures in optical lattices. Energy levels, filling factors and parameters dependence of gap solitons are explicitly calculated. Instabilities in the fermionic density induced by fluctuations in the bosonic component and their consequences on the bosonic spectrum are also discussed.

41 Quantum switches and quantum memories for matter wave solitons.

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Collaborators: V. Ahufinger, A. Mebrahtu, R. Corbalan

We will present our results on the interaction of matter wave Bose Einstein solitons created in optical lattices with "effective" potentials (barrier/well) corresponding to defects of the optical lattice. In this scenario the possibility of implementing a quantum switch in the case of an "effective" barrier and a quantum memory in the case of an "effective" well arises. The use of the defects as a way of controlling the interactions between two solitons is also reported.

42 Stability and Scattering of two-dimensional solitons in dipolar Bose-Einstein condensates.

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Bose-Einstein condensates of dipolar particles offer novel possibilities when compared to the up to now standard short-range interacting gases. At sufficiently low temperatures the physics of dipolar condensates is provided by a nonlocal nonlinear Schroedinger equation. Hence, dipolar condensates link the physics of cold gases with other nonlocal nonlinear media, as plasmas or nematic liquid crystals. We discuss in particular the conditions under which dipolar condensates allow for the creation of stable two-dimensional solitons which truly move in a two dimensional sense. The criteria for stability are analyzed in detail, showing that the inherent anisotropy of the dipolar interaction plays a significant role. Additionally we study the interaction of two unconnected 2D dipolar solitons placed at different sides of a transversal two-well trap, and their corresponding molecular potential. The inelastic nature of the soliton-soliton scattering is analyzed by means of numerical and variational calculations. In particular we discuss the appearance of a strong resonance in the inelastic scattering of the solitons. Finally, we comment on the fully 2D scattering case, in which inelastic spiraling and formation of orbiting solitons are predicted.

43 Subdiffractive Solitons in BECs in Spatio-Temporally Periodic Potentials.

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Collaborators: R.Herrero and V.J. de Valcarcel

A new type of matter wave diffraction management is presented that leads to sub-diffractive soliton-like structures. The proposed management technique uses two counter-moving, identical periodic potentials (e.g. optical lattices) for one-dimensional solitons, and respectively two or three pairs of periodic potentials for two or three dimensional solitons. For suitable lattice parameters a novel type of atomic band-gap structure appears in which the effective atomic mass becomes infinite at the lowest edge of an energy band. This way normal matter-wave diffraction (proportional to the square of the atomic momentum) is replaced by fourth-order diffraction, and hence the evolution of the system becomes sub-diffractive. We predict stable, collapse-free, one-, two- and three- dimensional spatial soliton-like structures in subdiffractive regimes, accomplished by diffraction management. We investigate the scaling laws, the stability, and the dynamical properties of these subdiffractive solitons.

44 Unbalanced Fermi gases.

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We discuss the recent experimental and theoretical progress in the understanding of the new superfluid phases that have been realized in an atomic Fermi gas with a resonant interaction between the two different spin species in the gas. We briefly review the crossover between a Bose-Einstein condensate of molecules and a Bose-Einstein condensate of Cooper pairs occurring for an equal density mixture and then discuss the physical issues presently observed for an unequal density of the two spin states in the gas.

45 Dipole-dipole interaction in a gas of ultracold chromium atoms.

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Collaborators: A. Griesmaier, T. Koch, S. Götz, M. Fattori, T. Pfau

We have investigated the expansion of a Bose-Einstein condensate of strongly magnetic Cr atoms. The long-range and anisotropic magnetic dipole-dipole interaction leads to a magnetostriction-like anisotropic deformation of the expanding Cr condensate which depends on the orientation of the atomic dipole moments. Our measurements are consistent with the theory of dipolar quantum gases and allow for a direct determination of e_{dd} - the ratio between dipole-dipole and contact interaction. The deduced value for the s-wave scattering length of Cr is in agreement with the results obtained by the analysis of Feshbach resonances. The dipole-dipole interaction can also be utilized in the condensate preparation procedure. As proposed by Kastler in 1950, a combination of optical pumping to the energetically lowest Zeeman substate and dipolar relaxation can be used to cool a dipolar gas. Using such a demagnetization cooling technique in a continuous way, we achieve efficiencies well beyond the ones of evaporative cooling.

46 Simple and efficient generation of gap solitons in Bose-Einstein condensates.

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Collaborators: E. Trippenbach, M. Matuszewski, W. Krolikowski, Y. Kivshar

We have revealed that the generation of matter-wave gap solitons in a repulsive Bose-Einstein condensate can be easier than expected. We propose and demonstrate numerically two generation schemes in which a robust, long-lived stationary wavepacket in the form of a matter-wave gap soliton is created in a repulsive Bose-Einstein condensate placed into a one-dimensional optical lattice. The same idea was applied to solitons formed in photorefractive media [1]. The suggested generation method looks simple and efficient, and it relies on a relaxation of the initial distribution of atoms to the appropriate soliton state. For this scheme, lifetime of the final state is limited only by the lifetime of the condensate. We presented a simple theoretical model to illustrate how the generation method works.

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[1] M. Matuszewski, C.R. Rosberg, D.N. Neshev, A.A. Sukhorukov, A. Mitchell, M. Trippenbach, M.W. Austin, W. Krolikowski, and Yu.S. Kivshar, Opt. Express 14, 254 (2006).

47 Stability and excitations of solitons in 2D Bose-Einstein condensates.

Author: Shunji Tsuchiya

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Collaborators: F. Dalfovo, C. Tozzo, and L. Pitaevskii

The small oscillations of solitons in 2D Bose-Einstein condensates are investigated by solving the Kadomtsev-Petviashvili equation which is valid when the velocity of the soliton approaches the speed of sound. We show that the soliton is stable and that the lowest excited states obey the same dispersion law as the one of the stable branch of excitations of a 1D gray soliton in a 2D condensate. The role of these states in thermodynamics is discussed.

48 Topological defects in superfluid 3He and their counterparts in other systems.

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Topological defects are generic in continuous media. We discuss exotic defects which have been observed (or predicted to exists) in superfluid phases of liquid 3He, and suggest observation of similar defects in ultracold gases. Among them: continuous vortex-skyrmion; solitons of different types; half-quantum vortex (Alice strings); meron (half of skyrmion); monopole; boojum (defect living on the surface of the superfluid or at the interface between two superfluids); spin vortex (vortex with circulation of spin current); topological defects with additional broken symmetry in the vortex core, such as vortex with ferromagnetic core and vortex with non-axisymmetric core; combined objects, such as: vortex terminating at hedgehog – Dirac monopole; soliton wall terminated by vortex; vortex terminating at the soliton; pair of vortices confined by piece of soliton or domain wall; spin-mass vortex – combined object with circulation of both spin and mass currents; vortex sheet – soliton filled with vortices (kinks) living within the soliton; etc.

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