International Joint Conference
SFB/TRR21 and IFRAF

Control of Quantum Correlations in Tailored Matter:

Common Perspectives of Mesoscopic Systems and Quantum Gases

Schloss Reisensburg, Oct. 3rd - 7th, 2007

General Information, Program, and Abstracts

Scope of the Conference

Over the last years, rapid progress has been made in the ability to control quantum gases as interacting quantum matter in well defined geometries at ultra-low temperatures. On the other hand, mesoscopic systems and devices show in many respects very similar behaviour. Therefore it is the goal of this conference to discuss the physics which is common to mesoscopic systems and quantum gases to improve our understanding of quantum matter and transfer the progress on quantum control into material science. The conference will focus on the following:

- Physics of condensed matter in ultracold and degenerate atom gases.
- Quantum phenomena in interacting dipolar or Rydberg gases.
- Kondo physics in mesoscopic systems.
- Quantum dots and quantum dot molecules.
- Microscopic ion and atom traps.
- Decoherence and non-equilibrium effects in correlated quantum systems.
- Superconducting quantum devices.

Program Committee

Reinhold Kleiner
Physikalisches Institut II, Universität Tübingen

Michèle Leduc
Laboratoire Kastler Brossel Ecole Normale Supérieure,
Département de Physique, Paris

Alejandro Muramatsu
Institut für Theoretische Physik III, Universität Stuttgart

Pierre Pillet
Laboratoire Aimé Cotton (LAC), Université de Paris-Sud, Orsay

Tilman Pfau
5. Physikalisches Institut, Universität Stuttgart

Christophe Salomon
Laboratoire Kastler Brossel Ecole Normale Supérieure,
Département de Physique, Paris

Wolfgang Schleich
Institut für Quantenphysik, Universität Ulm

Ferdinand Schmidt-Kaler
Institut für Quanteninformationsverarbeitung, Universität Ulm

Jürgen Weis
Max-Planck-Institut für Festkörperforschung, Stuttgart

Christoph Westbrook
Laboratoire Charles Fabry de l'Institut d'Optique (LCFIO), Orsay

Coordinator

Address	Prof. Dr. Tilman Pfau
	Universität Stuttgart
	5. Physikalisches Institut
	Pfaffenwaldring 57
	D-70569 Stuttgart
	Germany
Phone:	++49 (0)711 685 68025
FAX:	++49 (0)711 685 63810
Email:	tr21@physik.uni-stuttgart.de

Address	Dr. Jürgen Weis
	Max-Planck-Institut für Festkörperforschung
	Heisenbergstr. 1
	D-70569 Stuttgart
	Germany
Phone:	++49 (0)711 689 1329
FAX:	++49 (0)711 689 1010
Email:	j.weis@fkf.mpg.de

Seminar Site

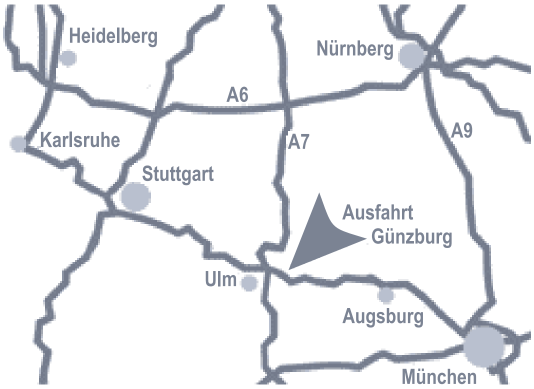
Address	Wissenschaftszentrum Schloss Reisensburg
	der Universität Ulm
	Bürgermeister-Johann-Müller-Strasse 1
	D-89312 Günzburg / Donau
	Germany
Phone:	++49 (0)8221 907-0
FAX:	++49 (0)8221 907-55
Email:	reisensburg@wzr.uni-ulm.de
Internet:	http://www.uni-ulm.de/reisensburg/

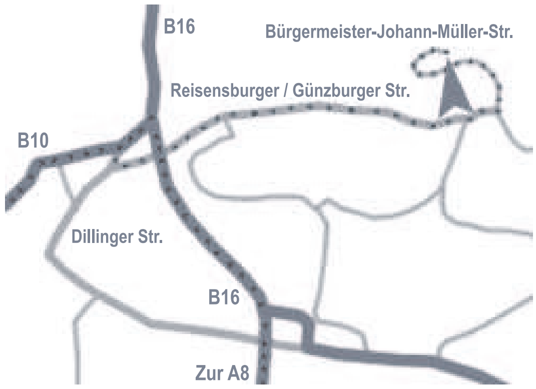
Internet Site of the Seminar

http://www.physik.uni-stuttgart.de/TR21/Workshop2007/index.htm

Travel Information

The conference will take place at Schloss Reisensburg in Germany.





Travelling by Car:

Take exit "Günzburg" (No. 67) of the Autobahn (A8) between Stuttgart-Ulm-Augsburg-Munich. Then follow the "Bundesstrasse" B16 towards Dillingen. Make a left turn at the intersection "Günzburg Nord" (before crossing the Donau (Danube) River) and look for a sign "Reisensburg". A left turn takes you through Reisensburg village. At the end of this street take a left turn, follow the road pass, a little village church and drive up to the castle.

Travelling by Train:

The closest train station to Schloss Reisensburg is Günzburg. The train station Günzburg is on the route Stuttgart-Ulm-Augsburg-Munich. There is no public transport from the train station Günzburg to Schloss Reisensburg available. You can use a taxi or a shuttle service which we will organize.

Shuttle Service:

If you want to use our shuttle service from Günzburg train station please call the following number when you arrive: 0172-7336472.

Program Schedule

Wednesday, October 3rd

18:00-19:30	Dinner
19:30-20:30	Welcome

Thursday, October 4th

8:30-9:05	Gora Shlyapnikov **Novel phases in strongly interacting Fermi gases**
9:05-9:30	Félix Werner **Three trapped atoms at a Feshbach resonance**
9:30-9:55	Christoph Weiss **Coherently controlled entanglement generation in a binary Bose-Einstein condensate**
	Coffee Break
10:30-11:05	Sergej Demokritov **Bose-Einstein condensation (BEC) of magnons**
11:05-11:30	Thierry Lahaye **A quantum ferrofluid**
11:30-11:55	Luis Santos **Dipolar gases: from nonlinear atom optics to strongly-correlated systems**
	Lunch
14:00-14:35	Klaus Sengstock **tba**
14:35-15:00	Olivier Gorceix **Trapping of cold bosonic and fermionic Chromium atoms: Towards a degenerate Boson-Fermion mixture of dipolar atoms**
15:00-15:25	Fedor Jelezko **Entanglement of single nuclear spins in diamond**
	Coffee Break
16:00-18:00	Poster
	Dinner
19:30-20:30	Wojciech Zurek **Dynamics of Symmetry Breaking in Non-equilibrium Phase Transitions and Bose-Einstein Condensates**

Friday, October 5th

8:30-9:05	Anatoli Polkovnikov **tba**
9:05-9:30	Philippe Bouyer **Ultracold Bose Gases in 1D Optical Disorder**
9:30-9:55	Michèle Leduc **Exotic molecules of ultracold metastable helium**
	Coffee Break
10:30-11:05	Bernhard Keimer **Quantum states in complex oxides: bulk versus interface**
11:05-11:30	Tobias Gaber **Thermal and resonant escape of fractional vortices in long Josephson junctions**
11:30-11:55	Francisco Perales **Coherent nanobeams of metastable atoms**
	Lunch
14:00-14:35	Christian Schönenberger **Spin and Charge Transport in Carbon Nanotube Hybrid Quantum Dots**
14:35-15:00	Tommaso Calarco **Quantum optimal control in atom and ion microtraps**
15:00-15:25	József Fortágh **Coherence with ultracold atoms at nanofabricated surfaces**
	Coffee Break
16:00-18:00	Poster
	Conference Dinner
19:30-20:30	Thomas Gallagher **Rydberg Atoms as Model Systems**

Saturday, October 6th

8:30-9:05	Martin Zwierlein **The Ground State of Imbalanced Fermi Mixtures**
9:05-9:30	Michael Grupp **Resonant Feshbach scattering of fermions in one-dimensional optical lattices**
9:30-9:55	Hans Peter Büchler **Strongly correlated quantum phases with cold polar molecules**

	Coffee Break
10:30-11:05	Matthias Troyer **The supersolid phase of matter**
11:05-11:30	Daniel Comparat **tba**
11:30-11:55	Matthias Weidemüller **Coherent processes in ultracold Rydberg gases**
	Lunch
14:00-14:35	Francis Robicheaux **Simulations of Many Interacting Rydberg Atoms**
14:35-15:00	Peter Schmelcher **Trapping and aligning ultracold Rydberg atoms in the quantum regime**
15:00-15:25	Jerome Lodewyck **tba**
	Coffee Break
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after breakfast	Sightseeing in Ulm

Abstracts

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Laboratoire de Physique Theorique et Modeles Statistique, Universite Paris Sud, Bat. 100, 91405 Orsay Cedex, Orsay, France
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Three trapped atoms at a Feshbach resonance
Félix Werner and Yvan Castin
Laboratoire Kastler Brossel, ENS, UPMC, CNRS, 24 rue Lhomond, 75231 Paris Cedex 05, France
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Niklas Teichmann[1] and Christoph Weiss[2]
[1] Institut Henri Poincaré, Centre Emile Borel, 11 rue P. et M. Curie, F-75231 Paris Cedex 05, France
[2] Laboratoire Kastler Brossel, École Normale Supérieure, Université Pierre et Marie-Curie-Paris 6, 24 rue Lhomond, CNRS, F-75231 Paris Cedex 05, France
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S.O. Demokritov
Nichtlineare Magnetische Dynamik, Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster Corrensstr. 2-4, 48149 Münster, Germany
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5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany
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Luis Santos

Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany **p. 26**

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To be announced

Klaus Sengstock

Institut für Laserphysik, Universität Hamburg,
Luruper Chaussee 149, D-22761 Hamburg, Germany **p. 27**

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Laboratoire de Physique des Lasers, CNRS UMR 7538, Université Paris Nord,
99 Avenue J.-B. Clément, 93430 Villetaneuse, France **p. 28**

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Fedor Jelezko

3. Physical Institute, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany **p. 29**

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Dynamics of Symmetry Breaking in Non-equilibrium Phase Transitions and Bose−Einstein Condensates

Wojciech H. Zurek

Mail Stop B213, Theory Division, LANL, Los Alamos, NM 87545, USA **p. 30**

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Anatoli Polkovnikov

Department of Physics, Boston University, USA **p. 31**

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Ultracold Bose Gases in 1D Optical Disorder

D. Clément[1], P. Bouyer[1]*, P. Lugan[1], M. Lewenstein[2], G. Shlyapnikov[3], and A. Aspect[1]

[1] Laboratoire Charles Fabry de l'Institut d'Optique,
CNRS and Univ. Paris-Sud, Campus Polytechnique,
RD 128, F-91127 Palaiseau cedex, France
[2] ICREA and ICFO-Institut de Ciències Fotòniques,
Parc Mediterrani de la Tecnologia,
E-08860 Castelldefels (Barcelona), Spain
[3] Laboratoire de Physique Théorique et Modèles Statistiques,
Univ. Paris-Sud, F-91405 Orsay cedex, France
Van der Waals-Zeeman Institute, Univ. Amsterdam,
Valckenierstraat 65/67, 1018 XE Amsterdam, The Netherlands **p. 32**

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Exotic molecules of ultracold metastable helium

Michèle Leduc*, Maximilien Portier, Steven Moal and Claude Cohen-Tannoudji

Laboratoire Kastler Brossel, Ecole Normale Supérieure,
24 rue Lhomond, 75231 Paris **p. 33**

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Bernhard Keimer

Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, Germany **p. 34**

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Thermal and resonant escape of fractional vortices in long Josephson junctions

T. Gaber[1], K. Buckenmaier[1], U. Kienzle[1], M. Siegel[2], D. Koelle[1], R. Kleiner[1] and E. Goldobin[1]

[1] Physikalisches Institut, Experimentalphysik 2, Universität Tübingen,
Auf der Morgenstelle 14, D-72076 Tübingen, Germany
[2] Institut für Mikro- und Nanoelektronische Systeme, Universität Karlsruhe (TH), Hertzstr. 16,
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Francisco Perales

Laboratoire de Physique des Lasers, Université Paris 13,
Av. J.B. Clément, 93430 Villetaneuse, France **p. 36**

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Christian Schönenberger*

Swiss Nanoscience Institute and Department of Physics at the University of Basel,
Klingelbergstr. 82, CH-4056 Basel, Switzerland **p. 37**

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Tommaso Calarco

Abteilung Quanteninformationsverarbeitung, Universität Ulm,
Albert-Einstein-Allee 11, D-89069 Ulm, Germany **p. 38**

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Physikalisches Institut der Universität Tübingen,
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T.F. Gallagher

Department of Physics, University of Virginia, Charlottesville, VA 22903 USA **p. 40**

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Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, MA 02139 **p. 41**

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M. Grupp[1], R. Walser[1], W. P. Schleich[1], A. Muramatsu[2], and M. Weitz[3]

[1] Institut für Quantenphysik, Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany
[2] Institut für Theoretische Physik III, Universität Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany
[3] Institut für Angewandte Physik der Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany **p. 42**

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Strongly correlated quantum phases with cold polar molecules

Hans Peter Büchler

in future: Theoretische Physik, Universität Stuttgart
now: Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria **p. 43**

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Matthias Troyer

Theoretische Physik, Schafmattstrasse 32, ETH Zurich, CH-8093 Zürich, Switzerland **p. 44**

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Daniel Comparat

Laboratoire Aimé Cotton, CNRS, Bâtiment 505,Campus d'Orsay, 91405 Orsay cedex, France **p. 45**

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Matthias Weidemüller*

Physics Institute, Albert-Ludwig University Freiburg, 79104 Freiburg, Germany **p. 46**

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Department of Physics, Auburn University, AL 36849-5311, USA **p. 47**

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Peter Schmelcher

Theoretische Chemie, Im Neuenheimer Feld 229, Universitt Heidelberg, D-69120 Heidelberg, Germany **p. 48**

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Jérôme Lodewyck

SYRTE, Observatoire de Paris, 77, avenue Denfert Rochereau, Paris, France — **p. 49**

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Ulrich Schöllwöck

Institute of Theoretical Physics, RWTH Aachen, D-52056 Aachen, Germany — **p. 50**

PART 2: Poster Contributions

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C. Weiß[1], R. Walser[1], W. P. Schleich[1], and J. Fortágh[2]

[1] Institut für Quantenphysik, Universität Ulm, D-89069 Ulm
[2] Physikalisches Institut, Universität Tübingen, An der Morgenstelle 14, D-72076 Tübingen — **p. 53**

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Physikalisches Institut, Universität Tübingen — **p. 55**

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Alexander Hübel, Jürgen Weis, and Klaus v. Klitzing

Max-Planck-Institut für Festkörperforschung,
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Bettina Berg[1], Lev Plimak[1], Murray K. Olsen[1,2], Michael Fleischhauer[3], and Wolfgang P. Schleich[1]

[1] Institut für Quantenphysik, Universität Ulm, Ulm, Deutschland
[2] ARC Centre of Excellence for Quantum-Atom Optics, School of Physical Sciences, University of Queensland, Brisbane, Australien
[3] Fachbereich Physik, Technische Universität Kaiserslautern, Kaiserslautern, Deutschland

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Daniela Denot, Lev Plimak, and Wolfgang P. Schleich

[1] Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Deutschland

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Poster Presentation 8

Strongly Correlated Fermions after a Quantum Quench

Salvatore R. Manmana[1], Stefan Wessel[2], Reinhard M. Noack[3], and Alejandro Muramatsu[2]

[1] Institute of Theoretical Physics (CTMC), Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland
[2] Institute for Theoretical Physics III, University of Stuttgart, Pfaffenwaldring 57/V, D-70550 Stuttgart, Germany
[3] Fachbereich Physik, Philipps-University Marburg, D-35032 Marburg, Germany

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Tunable quantum dots in InAs nanowires

Marc Scheffler[1], Stevan Nadj-Perge[1], Leo P. Kouwenhoven[1], Magnus T. Borgström[2], and Erik P.A.M. Bakkers[2]

[1] Quantum Transport Group, Kavli Institute of Nanoscience Delft, PO Box 5046, 2600 GA Delft, The Netherlands
[2] Philips Research Laboratories, Prof. Holstlaan 4, 5656 AA, Eindhoven, The Netherlands

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B. J. Dalton

ARC Centre for Quantum-Atom Optics and
Centre for Atom Optics and Ultrafast Spectroscopy,
Swinburne University of Technology, Melbourne, Victoria 3122, Australia

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Matt Kalinski

Department of Chemistry and Biochemistry, Utah State University, Logan, Utah 84322-0300, USA

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Oliver Mülken[1], Alexander Blumen[1], Thomas Amthor[2], Christian Giese[2], Markus Reetz-Lamour[2], and Matthias Weidemüller[2]

[1] Theoretische Polymerphysik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg i.Br., Germany
[2] Atomare & Molekulare Quantendynamik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg i.Br., Germany

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Fachbereich Physik, Universität Duisburg-Essen,
Lotharstraße 1, 47048 Duisburg, Germany

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Alexander Hoffmann[1], Axel Pelster[2], and Ednilson Santos[1]

[1] Institut für Theoretische Physik, Freie Universität Berlin,
Arnimallee 14, 14195 Berlin, Germany
[2] Fachbereich Physik, Universität Duisburg-Essen,
Lotharstraße 1, 47048 Duisburg, Germany

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Matthias Ohliger[1] and Axel Pelster[2]

[1] Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany
[2] Fachbereich Physik, Universität Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

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Fakultät für Physik, Universität Wien, Boltzmanngasse 5, 1090 Wien, Austria

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Department of Physics, Nanoscience Center,
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Department of Physics, University of Calcutta,
92, APC Road, Kolkata - 700 009, India

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G. Huber, T. Deuschle, W. Schnitzler, R. Reichle, K. Singer, and F. Schmidt-Kaler

Institute for Quantum Information Processing, University of Ulm,
Albert-Einstein-Allee 11, 89069 Ulm, Germany

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F. Karim Pour[1], M. Rigol[2], S. Wessel[1], and A. Muramatsu[1]

[1] Institut für Theoretische Physik III, Universität Stuttgart, Germany
[2] Department of Physics University of California, Santa Cruz, CA 95064, USA

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St. Schulz, U. Poschinger, G. Huber, R. Reichle, and F. Schmidt-Kaler

Universität Ulm, Institut für Quanteninformationsverarbeitung,
Albert-Einstein-Allee 11, 89069 Ulm, Germany

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G. Campagnano, P. Nägele, and U. Weiss

II. Institut für Theoretische Physik, Universität Stuttgart,
Pfaffenwaldring 57, D-70550 Stuttgart, Germany.

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Roman Bedau[1] and Ulrich Weiß[1]

[1] II. Institut für Theoretische Physik, Universität Stuttgart,
Pfaffenwaldring 57, 70550 Stuttgart, Germany

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Jürgen Berges[1], Kristan Temme[2], and Thomas Gasenzer[2],

[1] Institut für Kernphysik, Technische Universität Darmstadt,
Schlossgartenstrasse 9, 64289 Darmstadt, Germany
[2] Institut für Theoretische Physik, Universität Heidelberg,
Philosophenweg 16, 69120 Heidelberg, Germany

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Quantum Stochastic Resonance in Atomic Quantum Dots

Chris Ellenor

Univeristy of Toronto, Department of Physics,
60 St. George St., Toronto, ON, M5S 1A7, Canada

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Girish S. Setlur

Department of Physics, Indian Institute of Technology, Guwahati 781039, India

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T. E. Judd[1,2], R. G. Scott[1], G. Sinuco[1,2], A. M. Martin[3], and T. M. Fromhold[1]

[1] University of Nottingham, Nottingham NG7 2RD, United Kingdom
[2] Physikalisches Institut Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany
[3] University of Melbourne, Parkville, Vic. 3010, Australia

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Claus Hermannstädter[1], Lijuan Wang[2], Gareth J. Beirne[1], Armando Rastelli[3], Oliver G. Schmidt[3], and Peter Michler[1]

[1] Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany
[2] Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart, Germany
[3] Leibniz-Institut für Festkörper- und Werkstoffforschung, Helmholtzstr. 20, 01171 Dresden, Germany

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A. Perrin, H. Chang, V. Krachmalnikoff, M. Schellekens, V. Leung, D. Boiron, A. Aspect, and C.I. Westbrook

Laboratoire Charles Fabry de l'Institut d'Optique, CNRS, Univ Paris-Sud Campus Polytechnique, RD128, 91127 Palaiseau cedex, France

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Solitons and vortices in dipolar Bose Einstein condensates

Rejish Nath[1], Michael Klawunn[1], Paolo Pedri[2], and Luis Santos[1]

[1] Institut für Theoretische Physik , Leibniz Universität Hannover, Appelstr. 2, D-30167, Hannover, Germany
[2] Laboratoire de Physique Théorique et Modèles Statistiques, Université Paris Sud, 91405 Orsay Cedex, France

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Strongly-correlated bosons in ladder-like optical lattices

A. Arguelles

Leibniz Universität Hannover, Institut für Theoretische Physik, Appelstr. 2, D-30167 Hannover, Germany

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Strongly-correlated bosons in ladder-like optical lattices

R. Löw, R. Heidemann, U. Raitzsch, V. Bendkowsky, B. Butscher, and T. Pfau

5. Physikalisches Institut, Pfaffenwaldring 57, Universität Stuttgart, D-70569 Stuttgart, Germany

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Roughness suppression via rapid current modulation on an atom-chip

J.-B. Trebbia, C.L. Garrido Alzar, R. Cornelussen, C.I. Westbrook, and I. Bouchoule

Institut d'Optique, Campus polytechnique, RD 128, 91127 Palaiseau cedex, France

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Phase-dependent Landau-Zener tunneling in optical lattices of variable spatial symmetry

T. Salger, C. Geckeler, S. Kling, and M. Weitz

Institut für Angewandte Physik, Universität Bonn,
Wegelerstr. 8, D-53115 Bonn, Germany **p. 86**

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Quantum Dynamics of Atomic Coherence in Spinor Condensates

Lev Plimak

Institut für Quantenphysik, Universität Ulm,
D-89069 Ulm, Germany **p. 87**

PART 1: Oral Presentations

Novel phases in strongly interacting Fermi gases

Gora Shlyapnikov

Laboratoire de Physique Theorique et Modeles Statistique, Universite Paris Sud,
Bat. 100, 91405 Orsay Cedex, Orsay, France

Three trapped atoms at a Feshbach resonance

Félix Werner and Yvan Castin

Laboratoire Kastler Brossel, ENS, UPMC, CNRS,
24 rue Lhomond, 75231 Paris Cedex 05, France

We consider 3 atoms with short-range interactions of scattering length $a = \infty$, in an isotropic harmonic trap. In the zero-range limit, we solve the problem analytically [1], generalizing [2] and using an exact mapping [3] to the free space solution of [3].

For spin-1/2 fermions, all states are universal and stable with respect to three-body losses. For bosons, there are two types of eigenstates: non-universal, unstable states (similar to the Efimov states); but also universal, stable states.

We also study numerically the effect of a non-zero interaction range.

Experimentally, our results, in particular the existence of long-lived states for 3 bosons at a Feshbach resonance, could be checked at the triply occupied sites of a deep optical lattice.

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Coherently controlled entanglement generation in a binary Bose-Einstein condensate

Niklas Teichmann[1] and Christoph Weiss[2]

[1]Institut Henri Poincaré, Centre Emile Borel,
11 rue P. et M. Curie, F-75231 Paris Cedex 05, France

[2]Laboratoire Kastler Brossel, École Normale Supérieure,
Université Pierre et Marie-Curie-Paris 6,
24 rue Lhomond, CNRS, F-75231 Paris Cedex 05, France

Considering a two-component Bose-Einstein condensate in a double-well potential, a method to generate a Bell state consisting of two spatially separated condensates is suggested. For repulsive interactions, the required tunnelling control is achieved numerically by varying the amplitude of a sinusoidal potential difference between the wells. Both numerical and analytical calculations reveal the emergence of a highly entangled mesoscopic state [1].

The methods proposed to generates mesoscopic entanglement were previously suggested to control the superfluid-insulator transition [2, 3] or to investigate an analog of photon-assisted tunnelling in a double well potential [4].

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Bose-Einstein condensation (BEC) of magnons

S.O. Demokritov

Nichtlineare Magnetische Dynamik, Institut für Angewandte Physik,
Westfälische Wilhelms-Universität Münster
Corrensstr. 2-4, 48149 Münster, Germany

My talk will be devoted to Bose-Einstein condensation (BEC) of magnons. Magnons are quasi-particles corresponding to quanta of excitations in magnetically ordered media. They can be considered as bosons with a relatively weak interaction at temperatures far below the temperature of magnetic ordering. In general, to realize BEC, one can either decrease the temperature of the system or increase the density of the bosons. Usually this effect is observed at extremely low temperatures. In the experiments presented here we show that by using a technique of microwave pumping it is possible to excite additional magnons and to create a dense gas of quasi-equilibrium magnons. The value of the chemical potential in this gas of magnons is controlled by the pumping power. It increases with increasing pumping power. The chemical potential of the gas is determined directly from the direct study of magnon population at different energies. The magnon population has been investigated by means of Brillouin light scattering technique. From theoretical point of view BEC is observed, if the chemical potential of the system reaches the energy of the lowest state. Experimentally a very narrow peak of magnon population at the lowest magnon frequency is observed under these conditions. The measured width of the peak is five orders of magnitude smaller than that expected for the thermal distribution. The found overpopulation is associated with BEC of magnons and creation of a magnon condensate.

The thermalization in the gas of the pumped magnons caused by nonlinear multi-magnon scattering processes and leading to the magnon BEC is investigated with high temporal resolution. The pumping power necessary for the thermalization of magnons is determined. For pumping powers above this value the thermalization time has been found to decrease rapidly with power reaching the value down to 50 ns, which is much smaller than the typical magnon lifetime.

Coherence of the observed condensate is studied. Spontaneous emergence of coherence in magnons gas is detected.

A quantum ferrofluid

Thierry Lahaye, Tobias Koch, Bernd Föhlich, Marco Fattori, Jonas Metz, Axel Griesmaier, Stefano Giovanazzi, and Tilman Pfau

5. Physikalisches Institut, Universität Stuttgart,
Pfaffenwaldring 57, D-70550 Stuttgart, Germany

We report on the realization of a Chromium Bose-Einstein condensate (BEC) with strong dipolar interaction [1]. By using a Feshbach resonance, we reduce the usual isotropic contact interaction, such that the anisotropic magnetic dipole-dipole interaction between ^{52}Cr atoms becomes comparable in strength. This induces a change of the aspect ratio of the cloud, and, for strong dipolar interaction, the inversion of ellipticity during expansion – the usual "smoking gun" evidence for BEC – can even be suppressed. These effects are accounted for by taking into account the dipolar interaction in the superfluid hydrodynamic equations governing the dynamics of the gas, in the same way as classical ferrofluids can be described by including dipolar terms in the classical hydrodynamic equations. Our results are a first step in the exploration of the unique properties of quantum ferrofluids.

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Dipolar gases: from nonlinear atom optics to strongly-correlated systems

Luis Santos

Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany

To be announced

Klaus Sengstock

Institut für Laserphysik, Universität Hamburg,
Luruper Chaussee 149, D-22761 Hamburg, Germany

Trapping of cold bosonic and fermionic Chromium atoms: Towards a degenerate Boson-Fermion mixture of dipolar atoms

R.-S. Chicireanu, Q. Beaufils, B. Laburthe-Tolra, E. Maréchal, L. Vernac, J.-C. Keller, and O. Gorceix

Laboratoire de Physique des Lasers, CNRS UMR 7538, Université Paris Nord, 99 Avenue J.-B. Clément, 93430 Villetaneuse, France

Chromium atoms offer a ground state with a large magnetic dipole moment of six Bohr magnetons. Being accessible to laser manipulation, chromium offers the opportunity to deal with either its most abundant bosonic isotope ^{52}Cr or with its 9% abundant fermionic isotope ^{53}Cr. Chromium stands as a good candidate for studying new physics in the degenerate regime where the dynamics of the system is under the influence of important long range, anisotropic, dipole-dipole interactions. Actually, the bosonic isotope ^{52}Cr has recently been cooled down to degeneracy [1].

Over the past two years, we demonstrated and studied the magneto-optical trapping of ^{53}Cr, the simultaneous magneto-optical trapping of ^{52}Cr and ^{53}Cr [2]. We reported on the continuous accumulation and thermalization of up to 5.10^7 cold atoms in a finite depth magnetic quadrupolar trap [3]. Chromium atoms possess metastable D states. We use these states as a reservoir in which atoms leaking from the MOT accumulate and where they are shielded from the light-assisted inelastic collisions activated by the trapping MOT-laser beams.

During the past months, we loaded metastable and ground state ^{52}Cr atoms in optical dipole traps consisting of a focused 50W-cw-fiber laser beam either in a one dimension configuration [4] or in a crossed-beam configuration. Spin-polarization of the atoms into the true energetically lowest-state of the ground state is performed. This strongly inhibits detrimental two-body losses related to dipolar relaxation processes and will hopefully enable us to reach quantum degeneracy through forced evaporation. Recent results on evaporative cooling of optically trapped chromium atoms will be presented.

This work is supported by Conseil Régional Ile-de-France, MENESR, ANR, EU and IFRAF.

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Entanglement of single nuclear spins in diamond

Fedor Jelezko

3. Physical Institute, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany

Dynamics of Symmetry Breaking in Non-equilibrium Phase Transitions and Bose−Einstein Condensates

Wojciech H. Zurek

Mail Stop B213, Theory Division, LANL, Los Alamos, NM 87545, USA

Critical scalings of the *equilibrium* relaxation time and of healing length can be used to predict effects of the *non-equilibrium* dynamics of second order phase transitions. I will start with a summary of a theory of dynamics of the classical phase transitions based on this observation. It has found substantial experimental support, including recent experiments on BEC formation. I will also discuss dynamics of quantum phase transitions, and argue that gaseous Bose - Einstein condensates offer a perfect laboratory for more precise theoretical and experimental studies of the subject. Fundamental implications as well as applications of phase transition dynamics will be briefly noted.

To be announced

Anatoli Polkovnikov

Department of Physics, Boston University, USA

Ultracold Bose Gases in 1D Optical Disorder

D. Clément[1], P. Bouyer[1*], P. Lugan[1], M. Lewenstein[2], G. Shlyapnikov[3], and A. Aspect[1]

[1]Laboratoire Charles Fabry de l'Institut d'Optique,
CNRS and Univ. Paris-Sud, Campus Polytechnique,
RD 128, F-91127 Palaiseau cedex, France
[2]ICREA and ICFO-Institut de Ciències Fotòniques,
Parc Mediterrani de la Tecnologia,
E-08860 Castelldefels (Barcelona), Spain
[3]Laboratoire de Physique Théorique et Modèles Statistiques,
Univ. Paris-Sud, F-91405 Orsay cedex, France
Van der Waals-Zeeman Institute, Univ. Amsterdam,
Valckenierstraat 65/67, 1018 XE Amsterdam, The Netherlands

We study an interacting ultracold Bose gas in the presence of 1D disorder.

We show that the expansion of an initially confined interacting 1D Bose-Einstein condensate can exhibit Anderson localization in a weak random potential with correlation length σ_R. For speckle potentials the Fourier transform of the correlation function vanishes for momenta $k > 2\sigma_R$ so that the Lyapunov exponent vanishes in the Born approximation for $k > 1/\sigma_R$. Then, for the initial healing length of the condensate $\xi_{in} > \sigma_R$ the localization is exponential, and for $\xi_{in} < \sigma_R$ it changes to algebraic.

We also present the case of a non-expanding gas with repulsive interatomic interactions varying from zero to the Thomas-Fermi regime. We show that for weak interactions the Bose gas populates a finite number of localized single-particle Lifshits states, while for strong interactions a delocalized disordered Bose-Einstein condensate is formed. We discuss the schematic quantum-state diagram and derive the equations of state for various regimes.

* E-mail: philippe.bouyer@institutoptique.fr
www.atomoptic.fr

Exotic molecules of ultracold metastable helium

Michèle Leduc*, Maximilien Portier, Steven Moal and Claude Cohen-Tannoudji

Laboratoire Kastler Brossel, Ecole Normale Supérieure,
24 rue Lhomond, 75231 Paris

We shall present the recent results of photoassociation (PA) experiments dealing with a gas of helium atoms in the metastable state taken by evaporative cooling in the 2-10 μK range just above condensation. One-photon PA experiments provide a new and simple method to measure the atomic scattering length a by photo-mechanical effect: the cold cloud oscillates in the magnetic trap after receiving a kick from the PA pulse, the amplitude of the oscillations as a function of the light intensity can be interpreted in terms of the value of parameter a [1]. Two-photon PA experiments can also be used to measure a with even more accuracy [2], taking advantage of atom-molecule dark resonances as well as Raman signals. Such signals also provide information on the exotic molecule in the least bound state in the interaction potential of two spin-polarized metastable atoms. Their line widths are interpreted in terms of processes limiting the lifetime τ of the exotic molecule. We shall discuss the significant discrepancy between the experimental value found for τ [3] and two recent calculations of the Penning ionization rate induced by spin-dipole coupling [4],[5].

Finally we shall present the prospects of this helium experiment. First we plan to study how to modify the atomic scattering length through optical Feshbach resonance in an optical dipolar trap. Then we shall discuss the loading of the helium condensate into a 3D optical lattice in view of studying the superfluid-insulator quantum phase transition in real time through monitoring the Penning ionization products.

* Email: leduc@lkb.ens.fr

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Quantum states in complex oxides: bulk versus interface

Bernhard Keimer

Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, Germany

Thermal and resonant escape of fractional vortices in long Josephson junctions

T. Gaber[1], K. Buckenmaier[1], U. Kienzle[1], M. Siegel[2], D. Koelle[1], R. Kleiner[1] and E. Goldobin[1]

[1]Physikalisches Institut, Experimentalphysik 2, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany
[2]Institut für Mikro- und Nanoelektronische Systeme, Universität Karlsruhe (TH), Hertzstr. 16, D-76187 Karlsruhe, Germany

In long Josephson junctions with a κ-phase discontinuity, created by two current injectors, a fractional Josephson vortex (FJV) is spontaneously formed at the interface between the 0- and κ-part[1]. A FJV carries an arbitrary fraction $\Phi/\Phi_0 = \kappa/2\pi$ of the magnetic flux quantum $\Phi_0 \approx 2.07 \times 10^{-15}$ Wb. In contrast to fluxons, FJVs are pinned at the discontinuity point, yet become unstable if a bias current γ that is applied to the junction exceeds the characteristic threshold value $\gamma_c(\kappa)$[2, 3]. Then, a fluxon is torn off the discontinuity. This escape event can be considered as a Kramers like activation process[4]. We experimentally investigated the thermal activation of a FJV by high resolution measurements of the threshold current $\gamma_c(\kappa)$ distribution as a function of κ and temperature (down to 350 mK).

In addition, FJVs in underdamped systems are able to oscillate around their equilibrium position with characteristic eigenfrequencies. To experimentally determine the eigenfrequency we stimulated a FJV by irradiating our sample with microwaves. At resonance between microwave and eigenfrequency the junction switches to the resistive state. A measurement of the switching probability thus allows to determine the FJV eigenfrequency as a function of bias current and κ. We compare our results with the prediction of the perturbed sine-Gordon equation.

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Coherent nanobeams of metastable atoms

Francisco Perales

Laboratoire de Physique des Lasers, Université Paris 13,
Av. J.B. Clément, 93430 Villetaneuse, France

Spin and Charge Transport in Carbon Nanotube Hybrid Quantum Dots

Christian Schönenberger*

Swiss Nanoscience Institute and Department of Physics at the University of Basel, Klingelbergstr. 82, CH-4056 Basel, Switzerland

Charge transport at the ultimate limit is transport through a localized, zero-dimensional state. Such 0d objects, also called quantum dots or artificial atoms, can be embodied in various inorganic (semiconducting 2DEGs, synthesized nanoparticles) systems. However, transport studies through such artificial atoms have been restricted to normal electrodes. It is only since very recent, that we are able to fabricate superconducting and ferromagnetic electrodes to quantum dots. This has been made possible by carbon nanotube (CNT) quantum dots, which are exceptional in that they allow for hybrid quantum dots with both superconducting and ferromagnetic contacts. New physics emerge from studies of these hybrids in which spin-dependent phenomena can be studied in 0d.

After a brief introduction, in which I would like to stress the new possibilities offered by CNTs, I will focus on recent results from our research at Basel in the area of the proximity effect and spin-transport in two and multi-terminal devices.

For a recent review, see: C. Schönenberger, *Charge and Spin Transport in Carbon Nanotubes*, Semicond. Sci. Technol. **21**, p. 1-9 (2006).

* The work is a collaborative effort including the following researcher (in alphabetic order):
W. Belzig, C. Bruder, S. Cconka, A. Cottet, A. Eichler, M. Gräber, G. Gunnarsson, D. Keller, A. Kleine, T. Kontos, J. Nygaard, S. Oberholzer, S. Sahoo, J. Trbovic, and M. Weiss.

Quantum optimal control in atom and ion microtraps

Tommaso Calarco

Abteilung Quanteninformationsverarbeitung, Universität Ulm,
Albert-Einstein-Allee 11, D-89069 Ulm, Germany

The manipulation of ultracold atoms and ions in highly confined geometries gives the opportunity to prepare few-body interacting states with interesting properties and promising applications. Methods borrowed from quantum optimal control theory, as developed in the context of ultra-fast laser-assisted molecular reactions, prove particularly useful to tailor system dynamics according to a pre-defined goal. However, the experimental implementation of such techniques can be challenging, due to different sources of imperfection present in a real laboratory situation, such as for instance classical noise in the environment, fluctuations and inhomogeneous broadening of the control parameters, leakage to unwanted quantum degrees of freedom, coupling to thermal baths – all of this ultimately leading to decoherence. This talk will introduce the basic concepts and tools of quantum optimal control theory, present a series of recent applications to atoms and ions in microtraps, and discuss quantitatively the performance of several approaches to overcome each of the non-idealities characterizing a realistic context.

Coherence with ultracold atoms at nanofabricated surfaces

József Fortágh

Physikalisches Institut der Universität Tübingen,
Auf der Morgenstelle 14, D-72076 Tübingen

I am reporting about recent experiments on coherent manipulation of ultracold atoms at nanofabricated surfaces. These include the manipulation and state selective detection of single atoms as well as interferometry with Bose-Einstein condensates. Our current work focuses on the development of experimental techniques for preparing atoms at cryogenically cooled surfaces. The scientific objectives are the coupling of atoms to solid state nanodevices such as superconducting circuits, and the study of interactions between atoms and carbon nanotubes. Underlying theoretical concepts and the experimental progress will be reported.

Rydberg Atoms as Model Systems

T.F. Gallagher

Department of Physics, University of Virginia, Charlottesville, VA 22903 USA

In a Rydberg atom or molecule the valence electron is in a state of high principal quantum number n. Since the binding energy of the electron is $13.6/n^2$ eV, and the orbital radius is n^2 Å, a Rydberg atom differs from a ground state atom primarily in that the valence electron is in a large, loosely bound orbit. The large size and small binding energy endow Rydberg atoms with exaggerated properties compared to more normal atoms, those in the ground or first few excited states. Specifically, Rydberg atoms are far more sensitive to external perturbations than are normal atoms. As a result it is very easy to reach the regime in which externally applied fields are strong compared to the atomic field felt by the Rydberg electron, a regime which is difficult to reach using ground state atoms. More generally, the exaggerated properties also make it possible to manipulate Rydberg atoms in ways which would be impossible using ground state atoms, and it is possible to realize experiments which would be impossible in other systems.

The properties of Rydberg atoms and the methods will be briefly reviewed. Then illustrations of the use of Rydberg atoms will be given. In particular, field ionization, microwave multiphoton processes, and dipole-dipole energy transfer will be discussed. In Rydberg atom samples of temperature 1K or higher the dipole-dipole interaction can be observed in binary collisions between atoms, but in the frozen Rydberg gas interactions among more than two atoms are observed.

The Ground State of Imbalanced Fermi Mixtures

Martin Zwierlein

Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, MA 02139

Fermionic superfluidity, whether it occurs in superconductors, in helium-3 or inside a neutron star, requires pairing of fermions. In an equal mixture of "spin up" and "spin down" fermions, pairing can be complete and the entire system will become superfluid. When the two populations of fermions are unequal, however, not every particle can find a partner. Can superfluidity persist in response to such a population imbalance? If so, what would be the nature of this imbalanced superfluid state?

This question has been raised over forty years ago, at that time in the context of superconductors in a magnetic field. Chandrasekhar and, independently, Clogston found a limit of the upper critical field in superconductors, corresponding to an upper limit on the spin imbalance in Fermi mixtures, beyond which superfluidity breaks down. Sarma discussed a superfluid state supporting spin imbalance, but found it to be unstable. In 1964, Larkin and Ovchinnikov [1] and independently Fulde and Ferrell [2] proposed a novel superfluid state (LOFF-state), lower in energy than the BCS state, allowing for Fermi surface mismatch by forming Cooper pairs at finite momentum.

Forty years later, the debate surrounding the ground state of imbalanced superfluidity is still on-going. I will report on our studies of this intriguing question in a strongly interacting two-state mixture of trapped, ultracold fermionic atoms [3, 4, 5, 6]. The observation of vortices established superfluidity for imbalanced spin populations. When the fraction of unpaired atoms increased beyond a critical value, we observed the breakdown of the superfluid state, the Chandrasekhar-Clogston limit of superfluidity. Recently, we performed radio-frequency measurements showing a spectral gap even above the Clogston limit. This suggests that this breakdown is not associated with breaking of pairs, only with the loss of their long-range coherence, that cannot be restored even at zero temperature [6].

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Resonant Feshbach scattering of fermions in one-dimensional optical lattices

M. Grupp[1], R. Walser[1], W. P. Schleich[1], A. Muramatsu[2], and M. Weitz[3]

[1]Institut für Quantenphysik, Universität Ulm,
Albert-Einstein-Allee 11, D-89081 Ulm, Germany
[2]Institut für Theoretische Physik III, Universität Stuttgart,
Pfaffenwaldring 57, D-70550 Stuttgart, Germany
[3]Institut für Angewandte Physik der Universität Bonn,
Wegelerstraße 8, D-53115 Bonn, Germany

We consider Feshbach scattering of fermions in a one-dimensional optical lattice. By formulating the scattering theory in the crystal momentum basis, one can exploit the lattice symmetry and factorize the scattering problem in terms of center-of-mass and relative momentum in the reduced Brillouin zone scheme. Within a single band approximation, we can tune the position of a Feshbach resonance with the center-of-mass momentum due to the non-parabolic form of the energy band.

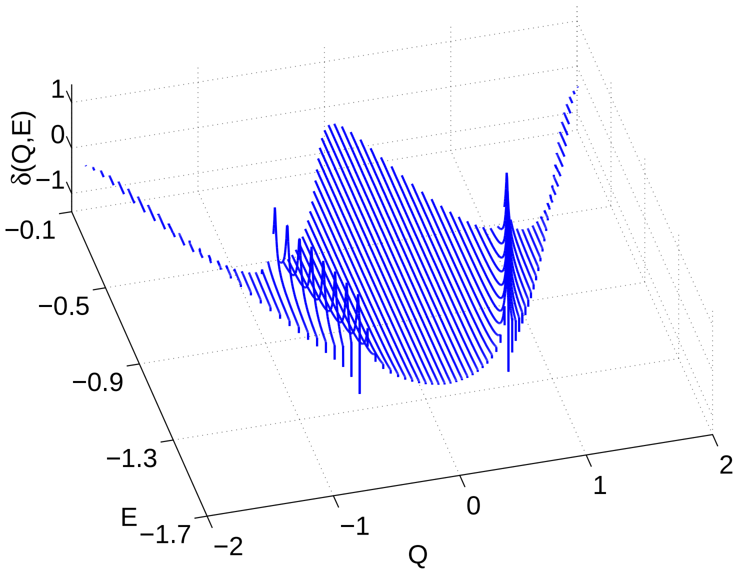

Figure 1: Even scattering phase-shift $\delta_e(E, Q)$ of a two-particle Bloch-wave versus energy E and center-of-mass momentum Q. One can see clearly Feshbach resonances symmetrically located around the Q-axis, which disappears when the bound state is outside the band.

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Strongly correlated quantum phases with cold polar molecules

Hans Peter Büchler

in future: Theoretische Physik, Universität Stuttgart
now: Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria

The quest for quantum degenerate polar molecules marks one of the latest developments in the rapidly evolving field of ultracold gases. A characteristic property of these heteronuclear molecules is a finite permanent electric dipole moment, which allows for driving an anisotropic dipole-dipole interaction between the particles using static electric fields and/or microwave fields. This strong and tunable long-range interaction offers the opportunity for wide application in designing strongly correlated systems. We will present some examples of possible strongly correlated systems which can be obtaine in polar molecules such as crystalline structures, and Hubbard models with three-body interactions. This crystalline phase has potential applications as an alternative method to optical lattice for creating lattice structures for cold atomic gases with the advantage of a natural honeycomb and triangular lattice structure and the coupling to phonons as a heat bath. Furthermore, the strong repulsion on short distances provide a reduction of inelastic collisions and consequently the long life-time makes these crystals very appealing for the usage as a quantum information storage devices.

The supersolid phase of matter

Matthias Troyer

Theoretische Physik, Schafmattstrasse 32, ETH Zurich, CH-8093 Zürich, Switzerland

The intriguing supersolid phase of matter, which exhibits simultaneously the seemingly contradicting properties of being solid (breaking translational symmetry) and superfluid (breaking gauge symmetry), has been proposed a long time ago but has eluded experimental detection so far. In this talk I will explain why the original hopeful candidate, solid Helium-4, does not exhibit a supersolid phase, and will discuss why ultracold polar molecules in triangular optical lattices provide the best hope for realizing this long-sought phase of matter.

To be announced

Daniel Comparat

Laboratoire Aimé Cotton, CNRS, Bâtiment 505,Campus d'Orsay, 91405 Orsay cedex, France

Coherent processes in ultracold Rydberg gases

Matthias Weidemüller*

Physics Institute, Albert-Ludwig University Freiburg, 79104 Freiburg, Germany

Due to the long-range character of the interaction between highly excited atoms, the dynamics of an ultracold gas of Rydberg atoms is entirely determined by van-der-Waals and dipole-dipole interactions. One outstanding property is the tunability of the strength and the character of the interactions with static electric fields. This allows one to explore the transition from a weakly coupled two-body system to a strongly coupled many-body system. The long-range interaction leads to many-body entanglement and has possible applications in quantum computing. In a recent series of experiments we studied coherent phenomena in an ultracold gas of Rydberg atoms under the influence of dipolar interactions. The Rydberg gas is formed in in a magneto-optical trap via cw two-photon excitation of Rb atoms into states with principal quantum number 30100 using cw lasers at 780 nm and 480 nm [1]. Our recent results include coherent Rabi oscillations between ground and Rydberg states and the observation of the dipole blockade in a mesoscopic sample [2,3], stimulated rapid adiabatic passage with 90 % transfer efficiency into Rydberg states [4], and studies of the many-body character of resonant energy transfer processes [5]. Our experiments also reveal the role of interaction-induced mechanical forces [6] as well as the influence of black-body radiation on the many-particle motional dynamics of the system [7].

* Work performed in collaboration with M. Reetz-Lamour, T. Amthor, K. Singer, J. Deiglmayr, S. Westermann, J. Denskat, C. Hofmann, A.L. de Oliveira, L.G. Marcassa.

Email: m.weidemueller@physik.uni-freiburg.de

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Simulations of Many Interacting Rydberg Atoms

F. Robicheaux and J. V. Hernández

Department of Physics, Auburn University, AL 36849-5311, USA

We report the results of simulations of the many atom wave function when a cold gas is excited to highly excited states. There are several interesting examples of this basic situation that have been experimentally investigated. The main common feature is that the atom-atom interaction energy becomes comparable to other energy scales in the system, e.g. photon line-widths. This leads to correlations in the electronic states of the atoms in the gas.

We simulated the many body wave function of this system by a direct numerical solution of Schrödinger's equation.[1, 2] This procedure is only appropriate when the coherence during the excitation step is maintained. Since the size of the Hilbert space grows at least as fast as 2^N (where N is the number of atoms), the computations can only proceed if the suitable approximations schemes are developed. We have incorporated methods that allow us to increase the accuracy of the calculation until convergence is achieved.

We have investigated several different examples of correlated Rydberg gases. The talk will focus on the properties of a gas that is excited to a single, specific Rydberg state. In this situation, the electronic states of different atoms can become correlated when the Rydberg-Rydberg interaction energy is comparable to or larger than the laser line width. If the interaction energy between excited atoms is large enough, the resultant energy shift will move the double excitation state out of resonance. This leads to a blockade effect[3] so that atoms within a certain distance of each other can not be excited simultaneously.

For different laser/atom properties, we investigated the fraction of atoms excited and the correlation of excited atoms in the gas for different types of excitation when the blockade region was small compared to the sample size. We also investigated the blockade effect when the blockade region is comparable to the sample size to determine the sensitivity of this system and constraints for quantum information. One particular topic investigated is the quantum phase gate. We examined the regime where the groups of atoms in the gate are neither totally within nor totally outside the blockade radius, thus exploring the tolerance of this system to imperfect conditions.

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Trapping and aligning ultracold Rydberg atoms in the quantum regime

Peter Schmelcher

Theoretische Chemie, Im Neuenheimer Feld 229, Universitt Heidelberg, D-69120 Heidelberg, Germany

We show that it is possible to confine and control the motion of Rydberg atoms in the quantum regime. A Ioffe-Pritchard field configuration is employed to demonstrate how tight traps alter the coupling of the Rydberg atom to the magnetic field. We solve the underlying Schrödinger equation of the system within a given n-manifold and show that for a sufficiently large Ioffe field strength the $2n^2$-dimensional system of coupled Schrödinger equations decays into several decoupled multicomponent spinor equations governing the center of mass motion. An analysis of the fully quantized center of mass and electronic states is undertaken. In particular, we discuss the situation of tight center of mass confinement. Superimposing an additional homogeneous electric field trapped Rydberg atoms can be prepared in long-lived electronic states exhibiting a permanent electric dipole moment of several hundred Debye. The resulting dipole-dipole interaction in conjunction with the radial confinement is demonstrated to give rise to an effectively one-dimensional ultracold quantum Rydberg gas with a mesoscopic interparticle distance. We derive analytical expressions for the electric dipole moment and the critical linear density of Rydberg atoms.

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To be announced

Jérôme Lodewyck

SYRTE, Observatoire de Paris, 77, avenue Denfert Rochereau, Paris, France

To be announced

Ulrich Schöllwöck

Institute of Theoretical Physics, RWTH Aachen, D-52056 Aachen, Germany

PART 2: Poster Contributions

Cold Atoms On Nanostructures

C. Weiß[1], R. Walser[1], W. P. Schleich[1], and J. Fortágh[2]

[1]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm
[2]Physikalisches Institut, Universität Tübingen, An der Morgenstelle 14, D-72076 Tübingen

A single-walled Carbon Nanotube (CNT) mounted on a lithographically fabricated chip defines a nearly perfect mechanical nano-oscillator. At common temperatures of the cooled chip surface ($T = 4\,\mathrm{K}$) it performs large classical oscillations. By exposing it to a stream of ultra-cold atoms or a BEC ($T_{kin} = 400\,\mu\mathrm{K}$, thermodynamic temperature $T = 100\,\mathrm{nK}$) we want to study the thermalization of the mechanical motion and if it can be cooled to its mechanical ground state. Therefore, we will present in this contribution the phonon modes of a CNT and simulate the interaction between the conducting CNT and a polarizable atom.

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The influence of number fluctuations on the transition from few to many bosons in (quasi)-1D

Michael Eckart, Reinhold Walser, and Wolfgang P. Schleich

Institute of Quantum Physics, Ulm University, D-89069 Ulm, Germany

A gas of (quasi)-one-dimensional bosons interacting via a repulsive delta function potential is investigated for finite particle numbers as well as in the thermodynamic limit. In particular we study the transition from few to many bosons in the presence of number fluctuations which are intrinsic to every experimental realization of a cold gas of atoms.

The interaction strength for our investigation ranges from the weakly correlated Gross-Pitaevskii regime to the strongly correlated Tonks-Girardeau regime. We compare results from various theoretical frameworks, starting with Lieb-Liniger theory for the thermodynamic limit and the Bethe-ansatz for a finite number of bosons [1]. Both theories describe a homogeneous gas of bosons.

These results are subsequently compared to an exact theory for trapped ultracold few-boson systems which is based on a multiconfigurational method [2]. We conclude our investigation by using an extended mean-field approach [3] to analyze various possibilities of implementing number fluctuations in theories which don't inherently include them.

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Superconducting Microtraps for Bose-Einstein Condensates

Brian Kasch, D. Cano, M. Kemmler, J. Fortagh, R. Kleiner, C. Zimmermann, and D. Kölle

Physikalisches Institut, Universität Tübingen

We present progress toward producing Bose-Einstein condensation in a superconducting magnetic microtrap. The scientific objective is the coupling of cold atoms to superconducting devices. An experimental system consisting of a BEC apparatus, and a Helium flow cryostat has been set up. A cloud of Rb-87 atoms will be evaporatively cooled in a magnetic trap and subsequently translated 5cm by means of optical tweezers to a magnetic microtrap generated on a niobium chip at 4,2 K.

We developed numerical methods for calculating magnetic fields in the vicinity of superconducting surfaces. Inhomogeneous current densities within the superconductor have been calculated using an energy-minimization procedure that relies on the London equations. Corresponding superconducting chips have been produced using optical lithography and lift-off techniques.

In a first experiment, we plan to measure the coherence time of a spin-polarized atomic cloud near a superconducting surface. Theoretical predictions show the spin-flip lifetime should be increased by several orders of magnitude as compared to the normal conducting state of the same wire. Current state of the experiment will be presented.

Atom-light interaction at 500 bar buffer gas pressure: approaching the thermal equilibrium of dressed states

U. Vogl, J. Nipper, and M. Weitz

Institut für Angewandte Physik, Universität Bonn,
Wegelerstraße 8, D-53115 Bonn, Germany

In usual atomic physics experiments the observed spectral linewidth of the fluorescence is many orders of magnitude below the room temperature, so that the excitation profile is widely unaffected by the statistical distribution function. We report on experiments in which by some 500 bar buffer gas pressure in a high pressure cell, a pressure broadened linewidth of a few nanometers of the rubidium D-lines is reached. With high light intensities of the exciting laser light the resonance lines are additionally power-broadened above values of $k_B T$ ($\simeq 1.1 \cdot 10^{13}$ Hz at 510 K cell temperature). In this parameter range we observe a strong asymmetry of the fluorescence line, in which the blue wings of the lines are strongly enhanced. An even stronger asymmetry is obtained when extrapolating the observed fluorescence signals towards infinite laser power. In this limit spontaneous decay processes, driving the system out of equilibrium, are negligible. We interpret the data as evidence for the coupled atom-light states (dressed states) to reach thermal equilibrium. The thermalisation is here realized by frequent atom-buffer gas collisions. Rate equations for the coupled atom-light system under frequent buffer gas collisions indicate strong deviations from the usual excitation spectrum when the system approaches thermal equilibrium. Our data agree reasonably well with this predictions. For the future, we expect interesting perspectives on the collective dynamics of hybride atom-light-quasiparticles (polaritons) in this novel high pressure system.

Two electrostatically coupled quantum dots as a pseudospin realization of the Anderson impurity model ?

Alexander Hübel, Jürgen Weis, and Klaus v. Klitzing

Max-Planck-Institut für Festkörperforschung,
Heisenbergstr. 1, D-70569 Stuttgart, Germany

Electrical transport on quantum dots, weakly coupled to leads, shows Coulomb blockade and single-electron charging effects. Due to the presence of spin-degeneracy, a Kondo-correlated state might form at even lower temperature, overcoming the Coulomb blockade. This is described by an analogy of the quantum dot system with the Anderson impurity model [1]. The conductance might even reach the conductance $2e^2/h$ of a spin-degenerate one-dimensional channel.

Two electrostatically coupled quantum dots with separate leads represent a pseudospin realization of the Anderson impurity model in certain parameter regimes [2]. Including the real spin degree-of-freedom, an SU(4) Kondo effect has been predicted for such a system [3]. As a consequence, both quantum dots become highly conductive at low temperature where single-electron tunneling is prohibited, however correlated electron recharging of both quantum dots is energetically possible.

In this presentation we give our status of experimentally proving the analogy between the Anderson impurity model and two electrostatically coupled quantum dot systems. Our former experiments were based on stacked quantum dot systems, allowing for a strong electrostatic coupling, however not allowing for full control of the tunnel barriers [4]. Recently we have developed laterally arranged quantum dot systems where this lack is overcome and, for the first time, even a high electrostatic coupling – the interdot capacitance takes one-third of the total dot capacitance – has been achieved [5].

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Commuting Heisenberg operators in the Wigner representation

Bettina Berg[1], Lev Plimak[1], Murray K. Olsen[1,2], Michael Fleischhauer[3], and Wolfgang P. Schleich[1]

[1]Institut für Quantenphysik, Universität Ulm, Ulm, Deutschland
[2]ARC Centre of Excellence for Quantum-Atom Optics, School of Physical Sciences, University of Queensland, Brisbane, Australien
[3]Fachbereich Physik, Technische Universität Kaiserslautern, Kaiserslautern, Deutschland

We discuss commuting Heisenberg operators as a response problem in the phase space. The Wigner representation [1] calculates averages of symmetrically ordered two-time operator pairs. In addition, Kubo's linear response relation [2] may be used to calculate expectation values of two-time commutators of Heisenberg operators. By combining these two facts, time-normally ordered bosonic correlation functions may be expressed in the Wigner representation. Furthermore, using the truncated Wigner representation [3] allows one to calculate these quantities approximately, yet with relative ease. This increases utility of the truncated Wigner representation, as time-normally ordered correlation functions are the quantities that are experimentally measured. We demonstrate these techniques for the one-dimensional Bose-Hubbard model, which has over the recent years turned into a standard model for cold atoms trapped in optical lattices [4].

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Quantisation of the electromagnetic field based on the Wheeler wave functional

Daniela Denot, Lev Plimak, and Wolfgang P. Schleich

[1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Deutschland

Quantisation of the electromagnetic field based on the Wheeler wave functional is discussed.

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Strongly Correlated Fermions after a Quantum Quench

Salvatore R. Manmana[1], Stefan Wessel[2], Reinhard M. Noack[3], and Alejandro Muramatsu[2]

[1]Institute of Theoretical Physics (CTMC), Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

[2]Institute for Theoretical Physics III, University of Stuttgart, Pfaffenwaldring 57/V, D-70550 Stuttgart, Germany

[3]Fachbereich Physik, Philipps-University Marburg, D-35032 Marburg, Germany

Using the adaptive time-dependent density-matrix renormalization group method, we study the time evolution of strongly correlated spinless fermions on a one-dimensional lattice after a sudden change of the interaction strength. For certain parameter values, two different initial states (e.g., metallic and insulating), lead to observables which become indistinguishable after relaxation. We find that the resulting quasi-stationary state is non-thermal. This result holds for both integrable and non-integrable variants of the system. As described in Ref. [1], the emerging quasi-stationary state is discussed in terms of generalized Gibbs ensembles.

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Tunable quantum dots in InAs nanowires

Marc Scheffler[1], Stevan Nadj-Perge[1], Leo P. Kouwenhoven[1], Magnus T. Borgström[2], and Erik P.A.M. Bakkers[2]

[1]Quantum Transport Group, Kavli Institute of Nanoscience Delft, PO Box 5046, 2600 GA Delft, The Netherlands

[2]Philips Research Laboratories, Prof. Holstlaan 4, 5656 AA, Eindhoven, The Netherlands

Quantum dots are a convenient approach to trap and manipulate individual electrons in a solid. Recently, quantum dots were employed for first steps towards quantum computation, where the spin of the trapped electrons is used as the qubit. So far, these experiments for the electrical manipulation of electron spins have been limited to quantum dots defined by local gating of 2DEGs in the GaAs material system. Here semiconducting nanowires offer a new approach to quantum dots where not only numerous different host materials can be employed, but furthermore heterostructures of materials that are incompatible for bulk devices can be grown. Nanowires therefore are promising candidates for more complex devices in the field of quantum information processing; this includes the combination of electrical and optical control and readout schemes.

Of the different semiconductor materials that can be grown as nanowires, InAs is particularly interesting due to the large g-factor and the strong spin-orbit coupling, and furthermore InAs is promising for devices because of the comparably easy processing for Ohmic contacts. Here we study the electronic transport in individual InAs nanowire devices at low temperatures. The nanowires are grown by MOVPE, and horizontal devices are individually designed and created using e-beam lithography. We use different gate geometries to tune the charge carrier density of the nanowire either globally or locally. In particular, we use local top gates to create barriers that can be used to define tunable quantum dots. Towards our final goal of spin manipulation of single electrons, we focus on a tunable double dot. We measure the electronic transport through the double quantum dot as a function of applied gate voltages to establish the different regimes accessible with a double dot: we present stability diagrams that demonstrate the full tunability from two independent dots to one combined dot, and we focus on the particularly interesting region of two interacting quantum dots where the interaction strength can be adjusted at will.

Decoherence and dephasing effects in Bose-Einstein condensates

B. J. Dalton

ARC Centre for Quantum-Atom Optics and
Centre for Atom Optics and Ultrafast Spectroscopy,
Swinburne University of Technology, Melbourne, Victoria 3122, Australia

Decoherence and dephasing effects due to boson-boson interactions are studied using a phase space method [1,2] in which the density operator is represented by a distribution functional of c-number fields related to the bosonic field operators. Decoherence effects are exhibited in quantum correlation functions [3], which determine many boson position measurements. The correlation functions are expressed as phase space averages involving the distribution functional, which satisfies a functional Fokker-Planck equation. Ito stochastic equations are obtained and phase space averages are replaced by stochastic averages. The method is applied to interferometry based on splitting and recombining Bose condensates. This extends earlier work [4] based on a two-mode approximation, which was restricted to small boson numbers and only allowed for dephasing effects due to interactions within two condensate modes.

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Engineering and simulation of quantum dots with strong time dependent and static fields and atoms - few electron theories of quantum phase transitions.

Matt Kalinski

Department of Chemistry and Biochemistry, Utah State University, Logan, Utah 84322-0300, USA

Several examples of quantum phase transitions in mesoscopic quantum dots and single and multi-electron atoms are presented upon the change of the external parameters like electric, magnetic or rotating electromagnetic fields. They are due to a sudden change of the properties of classical trajectories resulting in the explosion of phase space structures supporting coherent and squeezed single and multi electron states and can be explained within mathematical apparatus of few electron classical and harmonic quantum systems. Those can be single electrons in Coulomb field and the circularly polarized electromagnetic field in atoms with one single electron active as well as two or more electrons in helium and other atoms [1]. The magnetic field can be added to allow extra parameter for quantum engineering [2]. Those atoms can be shown to emulate harmonic quantum dots with impurities with an arbitrary effective charge as well as anti-harmonic quantum dots supporting the native Stark-Zeeman resonances unstable otherwise. Quantum projection operator quantum matrix theories as well as numerical simulations are also discussed.

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Survival Probabilities of Coherent Energy Transfer in Frozen Rydberg gases with Traps

Oliver Mülken[1], Alexander Blumen[1], Thomas Amthor[2], Christian Giese[2], Markus Reetz-Lamour[2], and Matthias Weidemüller[2]

[1]Theoretische Polymerphysik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg i.Br., Germany
[2]Atomare & Molekulare Quantendynamik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg i.Br., Germany

In the quest for signatures of coherent energy transfer we consider the trapping of excitations in frozen Rydberg gases within the continuous-time quantum walk (CTQW) framework. The dynamics takes place on a discrete network of N sites. Out of the N sites we assume $M \leq N$ sites to be traps and incorporate those phenomenologically into the CTQW formalism by a trapping operator, which leads to a new, non-hermitian Hamiltonian $\mathbf{H} = \mathbf{H}_0 + i\mathbf{\Gamma}$. The average CTQW survival probability $\Pi_M(t)$ for an excitation not to be trapped after some time t follows from the transition probabilities $\pi_{kj}(t)$ to go from site j to site k as

$$\Pi_M(t) \equiv \frac{1}{N-M} \sum_{j \notin \mathcal{M}} \sum_{k \notin \mathcal{M}} \pi_{kj}(t),$$

where $\mathcal{M}$ is the set of traps. For small M/N we show that $\Pi_M(t)$ displays different decay domains, related to distinct regions of the (imaginary part of the) spectrum of the Hamiltonian.

In the asymptotic limit, where $t \to \infty$, this leads in most cases to a simple exponential decay. However, this is not the case at intermediate, experimentally relevant times. We examplify our analysis with a discrete linear system of N sites with traps at each end (sites 1 and N, $M = 2$). In this case the decay at intermediate times obeys a power-law, which strongly differs from the corresponding classical exponential decay found in incoherent continuous-time random walk (CTRW) situations. Moreover, we show that in this time domain $\Pi_M(t)$ scales with N and is basically independent of the coupling strength between traps and non-trap sites.

In order to investigate the intermediate time domain and to differentiate between the CTQW and CTRW mechanisms, we present an experimental protocol based on a frozen Rydberg gas structured by optical dipole traps.

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Collective Excitations in a Trapped Bose-Einstein Condensate with Weak Quenched Disorder

Giovanni Falco, Axel Pelster, and Robert Graham

Fachbereich Physik, Universität Duisburg-Essen,
Lotharstraße 1, 47048 Duisburg, Germany

We study how the collective mode frequencies of a condensate in a harmonic trap are shifted by the presence of additional weak quenched disorder. To this end we apply the Huang-Meng theory [1, 2] to an inhomogeneous condensate in the Thomas-Fermi approximation [3]. This approach describes how local condensates in the minima interfere with the superfluid property of the condensate. We work out in detail the consequences for the hydrodynamic equations. In case of a Gaussian correlated disorder correlation we find that the negative shifts of the collective frequencies for the monopole and the dipole mode decrease rapidly with increasing correlation length. Thus, our theory makes it possible to experimentally test the predictions of the Huang-Meng theory.

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Visibility of Atomic Cloud Released from Optical Lattice

Alexander Hoffmann[1], Axel Pelster[2], and Ednilson Santos[1]

[1]Institut für Theoretische Physik, Freie Universität Berlin,
Arnimallee 14, 14195 Berlin, Germany
[2]Fachbereich Physik, Universität Duisburg-Essen,
Lotharstraße 1, 47048 Duisburg, Germany

At first we determine the phase boundary for the superfluid-Mott insulator transition for bosons in an optical lattice for finite temperatures. To this end we use a variational approach which takes into account quantum fluctuations beyond the mean-field level. In the zero-temperature limit our phase boundary lies between the mean-field result and recent high-precision Monte-Carlo simulations [1]. Furthermore, we extend the approach of Refs. [2, 3] to finite temperatures and present an analytical calculation for the interference pattern of an atomic cloud which expands from an optical lattice. The resulting visibility of the interference pattern indicates both short-range and long-range coherence in the Mott insulator and the superfluid regime, respectively. In addition, we account for inhomogeneity effects, which arise from an overall harmonic trap [4].

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Phase Diagram of Spin-1 Bosons in an Optical Lattice at Non-Zero Temperature

Matthias Ohliger[1] and Axel Pelster[2]

[1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

[2]Fachbereich Physik, Universität Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

We extend previous zero-temperature mean-field studies [1, 2] for the location of the superfluid-Mott insulator transition of spin-1 bosons in an optical lattice to finite temperatures. We find that the phase boundary changes continuously with the magnetization of the system and that a complete magnetization reproduces the phase diagram of spin-0 bosons [3, 4]. For an antiferromagnetic interaction, however, the zero-temperature limit of our phase diagram deviates significantly from the zero-temperature mean-field studies [1, 2], where a degenerate perturbation theory is applied for an odd number of bosons per site.

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Vorticity in rotating 2D Bose-Einstein condensates in the regime of strong coupling

Tanja Rindler-Daller

Fakultät für Physik, Universität Wien, Boltzmanngasse 5, 1090 Wien, Austria

When Bose-Einstein condensates are subjected to an external rotation, different vortex structures appear depending on the applied angular velocity. We consider the ground state within the Gross-Pitaevskii (GP) theory where the interaction between particles is modelled by a coupling constant $1/\varepsilon^2$ and we consider $0 < \varepsilon \ll 1$. Our starting point is the GP energy functional in the frame rotating with the external trap potential. In order to obtain a well-defined limit, all length scales are rescaled by an ε-dependent factor after which the angular velocity depends on ε: $\Omega = \Omega(\varepsilon)$. We show the following:

1. $\Omega \simeq C|\ln \varepsilon|$: We derive the leading orders of the GP energy and density and the critical angular velocities for a finite (independent of ε) number of vortices. Furthermore, we show that they are all single-quantized (i.e. the winding number is one for each vortex) and derive the vortex pattern. This regime is also studied in [1] for gases in anisotropic harmonic potentials which is extended to anisotropic (asymptotically) homogeneous potentials in [3].

2. $\Omega = C/\varepsilon$: We derive the leading orders of the GP energy and density rigorously and show that for a certain constant C a 'mesoscopic hole' of the order of the diameter of the condensate itself appears. The GP density is exponentially small there but outside this 'hole' remains still a finitely large (for $\varepsilon \to 0$) annulus where individual vortices reside.

3. $\Omega \gg 1/\varepsilon$: We derive the leading orders of the GP energy and density rigorously showing that for this order of magnitude a 'giant vortex' appears. Its vorticity is concentrated around the origin and fills out almost all of the condensate domain thereby expelling the gas to a narrow region around the boundary which shrinks as $\varepsilon \to 0$. The analysis in 2. and 3. is carried out for flat traps in [2] and for homogeneous traps in a forthcoming paper.

We have the following picture: Although the coupling goes to infinity, the number of vortices stays bounded as long as $\Omega \leq C|\ln \varepsilon|$ asymptotically. For $|\ln \varepsilon| \ll \Omega \ll 1/\varepsilon$, a dense lattice of vortices develops. Their number scales with Ω, hence is not bounded uniformly in ε any longer. However, there is still no leading order effect in the GP density since the size of the vortex cores decreases accordingly. Only for $\Omega \geq C/\varepsilon$ with a definite constant C depending on the trap, there appears a 'hole' on a mesoscopic scale where the GP density is exponentially small. Moreover, for $\Omega \gg 1/\varepsilon$ a giant vortex appears where the GP density is exponentially small in a region which fills out the whole domain in the limit $\varepsilon \to 0$ narrowing the condensate density to a delta distribution at the boundary. Thereby, we pinpoint the parameter domain in Ω where a giant vortex appears, which was not quite settled in the previous literature, by rigorous estimates.

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Collective excitations of a trapped Fermi-Fermi mixture

M. Reza Bakhtiari, L.M. Jensen, and P. Törmä

Department of Physics, Nanoscience Center,
University of Jyväskylä, Finland

Very recently the experimental achievement of multi components Fermi-Fermi mixture has been reported [1]. We investigate the collective excitations of a harmonically trapped Fermi-Fermi mixture across the Feshbach resonance. We discuss in some detail the behavior of monopole and quadrupole modes.

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Line Shape of Velocity Selective Pump-Probe Spectra of Rb

P. N. Ghosh, B. Ray, D. Bhattacharya, and S. Chakrabarty

Department of Physics, University of Calcutta,
92, APC Road, Kolkata - 700 009, India

We report study of Rb D_2 transitions in the presence of a pump beam in both Λ and V configurations. The system with two ground state hyperfine components and four upper hyperfine levels exhibits several velocity selective components for co- and counter-propagating cases. In addition to electromagnetically induced transparency (EIT), velocity selective hyperfine absorption enhancement peaks are observed [1] for the *Lambda*-type case. In the V-type case, the entire spectra dependent on the hyperfine splitting can be manipulated by tuning the pump frequency thus enabling the observation of transmission spectra for different velocity groups [2]. In this process a chosen set of velocity groups of atoms can be probed. The effect of a repumper frequency on the optically pumped transitions to the dark state is also studied. We also report theoretical simulation of the line shape from solutions of optical Bloch equations of the five-level atom interacting with the two radiations in different cases [3,4]. The results obtained from the room temperature study will be examined in the case of laser cooled atoms confined in a magneto-optic trap set up by us recently [5].

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Ion transport in a segmented Paul trap

G. Huber, T. Deuschle, W. Schnitzler, R. Reichle, K. Singer, and F. Schmidt-Kaler

Institute for Quantum Information Processing, University of Ulm,
Albert-Einstein-Allee 11, 89069 Ulm, Germany

Segmented linear Paul traps are one of the most promising candidates for the implementation of scalable quantum computing [1]. One key requirement for scalability is the ability to split strings of ions and transport ions carrying quantum information between different regions in a trap, e.g. a storing and a processing unit.

We present a segmented linear Paul trap meeting these requirements. It provides 15 pairs of electrodes generating almost arbitrary potentials along the trap axis including time dependent transport wells, non-harmonic splitting potentials and multiple trap configurations.

Single $^{40}Ca^{+}$-ions and strings of ions generated by isotope selective photoionization are confined in the radio frequency Paul trap, laser cooled and detected by their fluorescence on a CCD camera. Both radial and axial trap frequencies have been measured and agree with predicted values from numerical calculations with the precision of a few percent – a necessity for tailoring manipulation potentials. By applying time dependent voltages [2] to the 15 segment pairs we are able to control the ion positions over macroscopic distances in a deterministic way, thus splitting and merging ion chains and transporting single ions over a distance of several millimeters without loss with a success probability over 99.8%.

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Supersolids in confined fermions on one-dimensional optical lattices

F. Karim Pour[1], M. Rigol[2], S. Wessel[1], and A. Muramatsu[1]

[1]Institut für Theoretische Physik III, Universität Stuttgart, Germany
[2]Department of Physics University of California, Santa Cruz, CA 95064, USA

Using quantum Monte Carlo simulations, we show that density-density and pairing correlation functions of the one-dimensional attractive fermionic Hubbard model in a harmonic confinement potential are characterized by the anomalous dimension K_ρ of a corresponding periodic system, and hence, display quantum critical behavior. The corresponding fluctuations render the SU(2) symmetry breaking by the confining potential irrelevant, leading to structure form factors for both correlation functions that scale with the same exponent upon increasing the system size, thus giving rise to a (quasi-)supersolid.

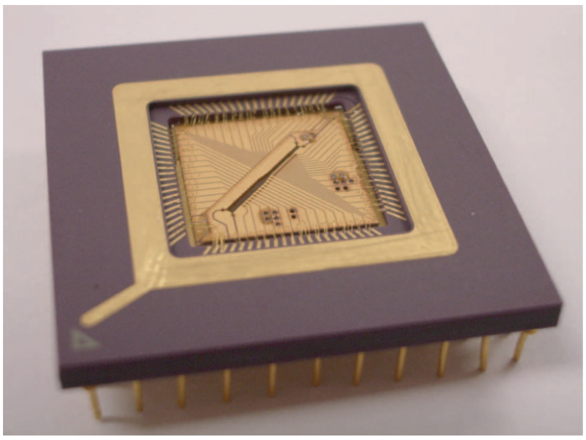
Microchip sized scalable segmented ion trap

St. Schulz, U. Poschinger, G. Huber, R. Reichle, and F. Schmidt-Kaler
Universität Ulm, Institut für Quanteninformationsverarbeitung,
Albert-Einstein-Allee 11, 89069 Ulm, Germany

Miniaturized multi-segmented linear ion traps are a promising architecture for quantum information processing in a scalable way [1]. The miniaturization of scalable linear Paul traps allows partitioning the trap region in storage and processing zones for qubits. The individual control of many qubits in different adjacent zones is fundamental for the implementation of large-scaled quantum algorithms.

We present a novel microchip sized multi-segmented linear Paul trap. The two-layer design is based on a laser cutted and structured Au/Al_2O_3-microstrucure. A RF frequency of 24 MHz, U_{pp}=360 V, allows radial confinement with frequencies of 2.5 MHz. In axial direction, DC control voltages of order ±10 V allow to generate arbitrary potentials with MHz trap frequencies. Two adjacent trap regions, a storage zone for loading and a processing zone for the realization of quantum algorithms, are formed by 31 segment pairs in total. Complex shuttling algorithms can be performed by precise control of the 62 individual DC segment electrodes. The area of the microchip trap is $(10\text{mm})^2$, the width of single electrode segments varies from 250μm in the loading zone and 100μm in the processing zone. The micrometer scaled multiplicity of the segment electrodes allows the creation of microscopic time-dependent arbitrary potentials for spatial qubit operations.

We discuss the technology for fabrication and operation of the trap. For this, we load and Doppler cool single ions and linear ion crystals. The trap frequencies are measured and compared in very good congruity with numerical simulations of the theoretical trap potentials based on boundary element calculations [2]. The $S_{1/2}\leftrightarrow D_{1/2}$ quadrupole transition, alternatively the Raman transitions between Zeeman levels of the ground state, is used for quantum state engineering. Currently, we observe quantum jumps on the $S_{1/2} \leftrightarrow D_{1/2}$ transition and aim for sideband spectroscopy and sideband cooling of ion crystals for reaching the ground state of motion. Sideband cooling will then allow investigating the cooling dynamics, heating rates in trap regions of different size and the heating rate due to a transport or a splitting of linear ion crystals. This way we complete characterization of the microchip ion trap.



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Relaxation and decoherence in coupled molecular magnets

G. Campagnano, P. Nägele, and U. Weiss

II. Institut für Theoretische Physik, Universität Stuttgart,
Pfaffenwaldring 57, D-70550 Stuttgart, Germany.

We study a system of two coupled molecular magnets modeled by spins which are coupled to each other and to independent Ohmic environment. The nonequlibrium dynamics is solved in the framework of the Feynman-Vernon method both in the limit of high temperatures, where the problem can be treated exactly, and at very low temperatures where the one-phonon approximation is valid. The results smoothly match at intermediate temperature. Relaxation and dephasing are given in the temperature range. The results are also relevant to the dynamics of coupled qubits.

Quantum Stochastic Resonance in Atomic Quantum Dots

Roman Bedau[1] and Ulrich Weiß[1]

[1]II. Institut für Theoretische Physik, Universität Stuttgart,
Pfaffenwaldring 57, 70550 Stuttgart, Germany

We study the mapping of an experimental setup onto the driven Spin–Boson model (SBM). The experimental setup consists of several independent atomic quantum dots (AQD) coupled to an one dimensional Bose–Einstein condensate (BEC). An optical lattice created by a standing wave of two opposite laser beams allows the formation of an array of AQDs which are superimposed to a trap holding an atomic BEC in a cigar–shaped volume. The atoms inside the quatum dots are coupled to the remaining atoms in the condensed phase via laser transitions.
In case of periodic driving the SBM exhibits quantum stochastic resonance (QSR) phenomena, where noise on a bistable system amplifies/suppresses the system's response to an external periodic signal. We show that QSR should be observable in a 1D–BEC within experimentally realizable conditions. Also non–linear effects like noise induced suppression of higher harmonics should be visible. Quite generally, a 1D–BEC can be used to analyse the SBM in a wide region of the parameter space.

Non-equilibrium dynamics with the 2PI effective action

Jürgen Berges[1], Kristan Temme[2], and Thomas Gasenzer[2],

[1]Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstrasse 9, 64289 Darmstadt, Germany
[2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

The 2-particle irreducible (2PI) effective action [1] allows to derive the set of quantum many-body equations of motion for the mean-field and the 2-point correlation functions. Its derivation is based on the Schwinger-Keldysh closed real-time path-integral for correlation functions. In any approximation consistent with the diagrammatic expansion scheme of the effective action, the dynamic equations, for a closed system, automatically conserve particle number and energy and are therefore ideal for studying dynamical evolution. The standard mean-field theories result as the leading-order classical statistical approximations of the quantum many-body problem. The role of quantum fluctuations is elucidated within the non-perturbative 2PI 1/N expansion in inverse powers of the number of field components N which allows to describe also strongly interacting systems. At this accuracy level memory-integrals enter the dynamic equations, which differ for quantum and classical statistical descriptions [2]. The non-perturbative qualities of the method are demonstrated for the dynamics of a strongly interacting gas in a lattice potential by comparing with exact quantum many-body calculations [3]. One obtains a 'classicality' condition for the many-body dynamics. This condition is exemplified by studying the nonequilibrium evolution and equilibration of a 1D gas [2, 4]. Some distinctive properties of quantum versus classical statistical dynamics [2] will be discussed, in particular for situations where quantum fluctuations dominate. The methods described are applicable to homogeneous and trapped systems in arbitrary dimensions, for Bosons as well as Fermions.

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Quantum Stochastic Resonance in Atomic Quantum Dots

Chris Ellenor

Univeristy of Toronto, Department of Physics,
60 St. George St., Toronto, ON, M5S 1A7, Canada

The collision of a BEC with a one-dimensional dipole barrier is used to probe scattering processes in the "non-asymptotic" regime, and the results are extended to to a novel tomographic technique. Despite classical predictions that an ensemble interacting with a repulsive potential will necessarily be reduced in its momentum, it has been proposed [1] that a quantum mechanical system will show a transitory enhancement of high-momentum components. This prediction is probed through the collision of a Bose-Einstein condensate with a repulsive, one-dimensional dipole barrier. The instantaneous removal of the dipole potential during the collision, and subsequent time-of-flight measurement probe the momentum state of the condensate during the collision. It is also noted that if the cloud is allowed a period of dispersion, or chirp, before the collision, momentum components are allowed to separate in space, and will interfere with the new "enhanced" momentum components excited by the collision. This interference is studied, and is demonstrated to be a novel method for measurement of condensate phase. Data is presented on the transitory enhancement of high-momentum components and phase measurement of the condensate. This new technique for measurement of wavefunctions is compared to existing techniques in both atom and laser optics, and further work on the measurement of density matrices is discussed.

Describing Fermions Using Commuting Variables : From Sea-Bosons to Quantum Hydrodynamics

Girish S. Setlur

Department of Physics, Indian Institute of Technology, Guwahati 781039, India

This poster describes a nonperturbative method for studying fermions in one and higher dimensions using commuting variables. The formalism developed over the last decade is described and some recent applications such as to the X-ray edge problem [G.S. Setlur and V. Meera, Solid State Commn. vol. 143, pp 182 (2007)] and to the problem of superconductivity is described.

Reflecting, Diffracting and Focusing Bose-Einstein Condensates with Atom Chips

T. E. Judd[1,2], R. G. Scott[1], G. Sinuco[1,2], A. M. Martin[3], and T. M. Fromhold[1]

[1]University of Nottingham, Nottingham NG7 2RD, United Kingdom
[2]Physikalisches Institut Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany
[3]University of Melbourne, Parkville, Vic. 3010, Australia

Combining the coherent matter waves of a Bose-Einstein condensate (BEC) with the versatility of condensed matter structures provides an exciting interface with great potential for the development of atom optics devices [1, 2]. However, unlike simple matter waves, BECs have non-linear inter-atomic interactions which can ruin attempts to manipulate them. Additionally, interactions between BECs and surfaces can be troublesome. It is therefore vital to understand the role of these effects and to find ways of reducing their influence.

We have tested BECs with both repulsive and attractive atomic interactions with a range of surface-based optical devices including atomic mirrors, diffraction gratings, focusing lenses and chaotic apertures. The numerically intensive nature of this work has led us to develop novel supercomputer techniques to simulate BECs. In all cases we find accessible regimes in which the BEC approximates a well-behaved single-particle picture, allowing for simple, coherent manipulation of the BEC and favourable atom-surface interactions. However, we also find regimes in which the interactions dominate the behaviour, causing a range of interesting phenomena and explaining anomalous experimental results [3].

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Controllable Coupling and Photoluminescence Polarization Properties in Individual Lateral InGaAs Quantum Dot Molecules

Claus Hermannstädter[1], Lijuan Wang[2], Gareth J. Beirne[1], Armando Rastelli[3], Oliver G. Schmidt[3], and Peter Michler[1]

[1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany
[2]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart, Germany
[3]Leibnitz-Institut für Festkörper- und Werkstoffforschung, Helmholtzstr. 20, 01171 Dresden, Germany

We demonstrate the presence of quantum coupling in lateral InGaAs quantum dot molecules (QDMs) that have been grown using a unique technique combining molecular beam epitaxy and atomic-layer precise *in-situ* etching [1]. This etching process results in the formation of nanoholes, which act as nucleation centers for the formation of QDMs aligned in the $[1\bar{1}0]$ crystal direction. The QDMs are subsequently overgrown with GaAs. Selective etching of the GaAs cap layer enables us to reveal the "real" morphology of QDMs after the encapsulation and subsequent annealing, which is difficult to determine by other methods.

The two individual quantum dots (QDs) that form a single molecule are coupled along the $[1\bar{1}0]$ axis. This allows for deterministic application of lateral electric fields along the coupling axis in order to tune the electron tunneling rates and therefore the degree of molecular coupling [2]. The presence of coupling in these quantum systems has been shown using photon statistics methods, i.e. by measuring a clear suppression of inter-dot coincidence events at zero time-delay in the second-order cross-correlation function $g^{(2)}_{a,b}(\tau) = \frac{\langle :I_a(t)I_b(t+\tau): \rangle}{\langle I_a(t)I_b(t) \rangle} < 0.5$, where the indices a and b represent any combination of two photons with different energies and therefore different radiative recombination processes in the same QDM. Furthermore, it is possible to reversibly intensity switch between characteristic excitonic photoluminescence (PL) lines by applying a lateral electric field. Consequently, the QDM can be used as a wavelength-tunable single-photon source.

In recent experiments we have focused on the polarization properties of the QDM PL in order to gain insight into the spatial distribution of the exciton wave function and the spin properties of the charge carriers confined to the molecules. This is studied by projection of the QDM PL into both a rotatable linear and circular analyzing basis. Depending on the fine structure splittings, which are assumed to be on the order of a few μeVs up to tens of μeVs, a high-resolution setup, such as, a scanning Fabry-Perot interferometer, is needed to resolve these effects.

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Observation of atom pairs in spontaneous four-wave mixing of two colliding Bose-Einstein condensates

A. Perrin, H. Chang, V. Krachmalnikoff, M. Schellekens, V. Leung, D. Boiron, A. Aspect, and C.I. Westbrook

Laboratoire Charles Fabry de l'Institut d'Optique, CNRS, Univ Paris-Sud Campus Polytechnique, RD128, 91127 Palaiseau cedex, France

Recent years have seen the emergence of quantum atom optics, that is the extension of the many analogies between atom optics and traditional optics to the quantum optical domain in which phenomena like vacuum fluctuations and entanglement play a central role. In optics the advent of correlated photon pairs [1] has provided a fruitful avenue of investigation, with examples including single photon sources and entangled states [2]. Partly inspired by this work, there have been many proposals concerning atom pairs, especially the production and observation of entanglement.

Here, we report on the observation of individual atom pairs with opposite velocities produced in the collision of two condensates. A time and position resolved, single atom detector [3] permits us to reconstruct the 3-dimensional distribution of the scattered atoms: a spherical shell in velocity space. We also reconstruct the two-particle correlation function in 3D and find a strong correlation between atoms emitted back-to-back. This process can be interpreted as a spontaneous four-wave mixing process constrained by a phase matching condition as in the non-linear optical analog which produces twin photons [2]. It can also be seen as the result of pairwise elastic collisions between atoms, constrained by momentum conservation. We measure the width of the velocity correlation function for a back-to-back atom pair and show that it can be roughly understood from the uncertainty limited momentum spread of the colliding BECs.

In addition, we observe a Hanbury-Brown and Twiss correlation for collinear momenta, which permits an independent measurement of the size of the pair production source and thus the size of the spatial mode. The back-to-back pairs occupy very nearly two oppositely directed spatial modes, a promising feature for future quantum optics experiments.

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Solitons and vortices in dipolar Bose Einstein condensates

Rejish Nath[1], Michael Klawunn[1], Paolo Pedri[2], and Luis Santos[1]

[1]Institut für Theoretische Physik , Leibniz Universität Hannover,
Appelstr. 2, D-30167, Hannover, Germany
[2]Laboratoire de Physique Théorique et Modèles Statistiques,
Université Paris Sud, 91405 Orsay Cedex, France

We discuss the physics of solitons and vortices in matter waves in the presence of Dipole-dipole interaction. Due to the non-local non-linearity of the dipolar interaction, there is fundamentally new and interesting physics came up in the study of solitons and vortices in matterwaves. Dipolar interaction stabilizes the two dimensional(2D) bright solitons in BEC, which is not possible just with short range contact interactions[1]. A remarkable consequence of dipolar interaction is that the 2D solitons placed in unconnected layers are not independent, which leads to an interesting scattering physics between them, contrary to the short range interacting ones[2]. We discuss that the interlayer interaction leads to an effective molecular potential between the disconnected solitons, which includes inelastic fusion into soliton molecules, inelastic resonances, spiraling of 2D solitons similar to the one observed experimentally in photorrefractive materials. We also discuss the possibility of stabilizing the 3D homogeneous dark solitons in dipolar BEC, in the presence of an optical lattice in the nodal plane of the soliton [4].

Finally we discuss the physics of vortex lines in dipolar BEC. Contrary to the short range interacting ones, the 3D nature of the vortices are significantly important in dipolar ones, especially it effects the size of the vortex core and the stability of the transverse modes of the vortex line. We discuss the appearence of a roton minimum in the spectrum of tranvserse modes, in the presence of an external periodic potential along the vortex line. We discuss the appropriate conditions at which this roton minimum may eventually lead to an instability of the vortex line, opening new scenarios for vortices in dipolar gases[3].

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Strongly-correlated bosons in ladder-like optical lattices

A. Arguelles

Leibniz Universität Hannover, Institut für Theoretische Physik,
Appelstr. 2, D-30167 Hannover, Germany

We analyze the physics of strongly-correlated bosons in ladder-like optical lattices. We first consider the equilibrium properties of nonlocally coupled legs, showing the appearance of pair-superfluid phases. The pair-superfluid significantly modifies the boundaries of Mott-insulator phases, which eventually show a marked re-entrant behavior even in 2D arrangements. This effect leads to a counter-intuitive behavior of the Mott-regions in inhomogeneous potentials. In the second part of the poster, we discuss out-of-equilibrium ladder-like systems. In particular, we investigate Josephson-like oscillations between initially unbalanced legs, and study the effect of the in-leg correlations on the transversal oscillations for different interaction regimes.

Strongly-correlated bosons in ladder-like optical lattices

R. Löw, R. Heidemann, U. Raitzsch, V. Bendkowsky, B. Butscher, and T. Pfau

5. Physikalisches Institut, Pfaffenwaldring 57,
Universität Stuttgart, D-70569 Stuttgart, Germany

We performed experiments on the coherent dynamics of Rydberg excitation in thermal clouds of ^{87}Rb for a wide range of atomic densities, single-atom Rabi-frequencies and excitation times in a specialized vacuum chamber. We further observed a clear signature of the phase transition to a Bose-Einstein condensate in the fraction of excited Rydberg atoms when cooling the thermal cloud below T_c. In our experiments the sample size is bigger than the so called blockade radius, which is defined as the interatomic distance where the interaction energy becomes equal to the power broadened linewidth of the excitation.

The obtained results are in excellent agreement with our theoretical understanding of the system. A single atom exposed to resonant excitation light will coherently oscillate with the single-atom Rabi frequency Ω_0 between the ground and excited state. An ensemble of N non-interacting atoms gives just N times the single-atom excitation dynamics. But if for all members of the ensemble the interaction between atoms in the excited state is much stronger than the linewidth of the excitation, the ensemble can carry only one excitation. As the excitation can be located at any of the available atoms this collective state is of the form:

$$|\psi_e\rangle = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} |g_1, g_2, g_3, ..., e_i, ..., g_N\rangle, \qquad (1)$$

where g_k indicates an atom numbered k in the ground state and e_i atom i in the excited state. Therefore in this strong blockade regime the ensemble is excited collectively and oscillates with the collective Rabi frequency $\sqrt{N}\Omega_0$ between the ground state and the collective excited state $|\psi_e\rangle$. In this sense the ensemble of N atoms acts like a 'superatom' [1] with a transition dipole moment which is enhanced by a factor $\sqrt{N}$ as compared to the individual atoms. We have observed this mesoscopic quantum effect by varying the ground state density n_g and the coherence of the excitation by varying the Rabi-frequency Ω_0 in a thermal cloud [2]. Analogous size effects are expected in other mesoscopic systems carrying a single excitation quantum only, like an exciton in a quantum dot or a dark state polariton excited by a single photon in an ensemble of atoms. The demonstrated scalability of the system will enable studies of size dependent quantum correlations and decoherence effects in strongly interacting non-equilibrium situations.

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Roughness suppression via rapid current modulation on an atom-chip

J.-B. Trebbia, C.L. Garrido Alzar, R. Cornelussen, C.I. Westbrook, and I. Bouchoule

Institut d'Optique, Campus polytechnique, RD 128, 91127 Palaiseau cedex, France

Atom chips, devices which trap and guide atoms with micro-fabricated structures on a substrate, hold enormous promise for the applications of cold atoms and for the exploration of new physical regimes of degenerate gases. For applications, their small size facilitates the design of a large variety of structures and functionalities. For fundamental studies, the strong confinement possible on an atom chip permits, for example, the study of low dimensional gases. To exploit the full potential of these devices, atoms must often be close to the material structures they contain. This proximity however, renders atom chips highly sensitive to defects which produce roughness in the trapping potential. In the case of current carrying wires, most of these defects are due to the wires themselves. Advances in fabrication procedures have steadily improved wire quality, but the roughness of the trapping potential remains a problem. On our experiment, we have demonstrate a method ?which nearly eliminates the longitudinal potential roughness of a magnetic wire trap by rapid current modulation. This idea is reminiscent of the TOP trap in the sense that the atoms see a time averaged potential. The wire configuration here is such that the rough potential component rapidly oscillates and averages to zero. We have measured a reduction factor of at least 5 without noticeable atom loss or heating. Those results are in agreements with a theoretical study of the limitations of the method which show that this technique is very robust.

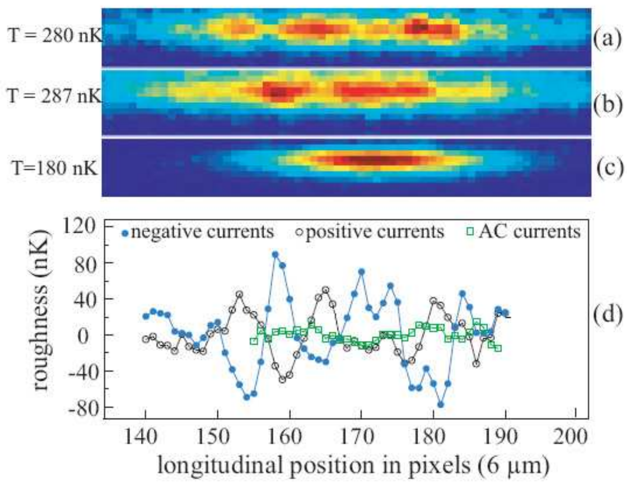

Figure 1: Absorption images of a thermal cloud for negative DC (a), positive DC (b), and AC currents (c), respectively. Plotted is the number of atoms per pixel (pixel size is $6 \times 6\ \mu m^2$). In (d), the potential roughnesses are extracted from longitudinal profiles using Maxwell-Boltzmann's distribution.

Phase-dependent Landau-Zener tunneling in optical lattices of variable spatial symmetry

T. Salger, C. Geckeler, S. Kling, and M. Weitz

Institut für Angewandte Physik, Universität Bonn,
Wegelerstr. 8, D-53115 Bonn, Germany

We report experimental results on transport properties of Bose-Einstein condensates in periodic optical potentials of variable asymmetry. By studying the Landau-Zener effect and Bloch oscillations, we have explored the band structure of both ratchet-type asymmetric and symmetric optical potentials. In earlier work, quantum transport in "conventional" sinusoidal lattices has proven to be a powerful technique for characterisation of the band structure. To realize lattice potentials of variable asymmetry, we superimpose the conventional lattice potential of $\lambda/2$ spatial periodicity with a fourth-order optical potential of $\lambda/4$ spatial periodicity. The high periodicity lattice is realized using dispersive properties of multiphoton Raman transitions. To study quantum transport in such Fourier-synthesized lattice potentials the periodic potential is accelerated.

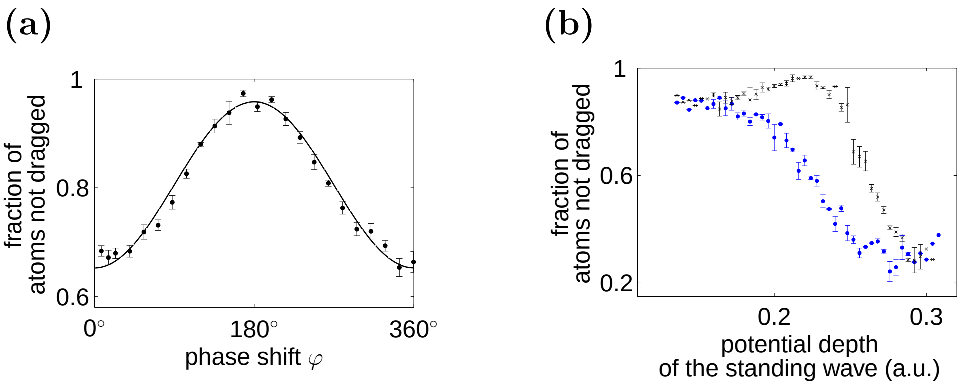

Figure 1: (a) Phase dependency of the number of atoms tunneling between the first and second excited Bloch band. (b) Dependence of the tunneling rate on the potential depth of the optical standing wave for a phase difference between two- and four-photon potentials of 0° (dots) and 180° (crosses).

We could clearly observe a sinusoidal dependence of the tunneling rate between the first and second excited Bloch band. If the phase difference between the two harmonics reaches 180°, corresponding to a potential form resembling a periodic sequence of dimples, nearly all atoms were observed to tunnel to the higher Bloch band. The tunneling decreases for other phase values, as shown in Fig. 1a, and a minimum is reached for a phase difference of 0°, corresponding to a potential form consisting of a periodic sequence of hills. Two extremes at minimal and maximal tunneling are investigated more in detail by variation of the potential depth of the optical standing wave, yielding results as shown in Fig. 1b. For a phase difference near 0° a simple exponential dependence of the tunneling rate on the potential depth is observed. In contrast, for a phase difference of 180°, the tunneling rate reaches its maximum at a two-photon potential value different from zero, while decreasing for smaller and higher potential values. Our experimental results are in agreement with theoretical calculations.

Quantum Dynamics of Atomic Coherence in Spinor Condensates

Lev Plimak

Institut für Quantenphysik, Universität Ulm,
D-89069 Ulm, Germany

Evolution of atomic coherence in spin-1 condensates is discussed. It is argued that time-resolved measurements of the coherence allow one access to second-order correlations in the condensate.