Program Title

Quantum Degenerate Dilute Systems

Program Acronym

QUDEDIS

Principal Applicants

Prof. Dr. Martin Wilkens, Universität Potsdam, GERMANY

Prof. Dr. Maciej Lewenstein, Universität Hannover, GERMANY

Summary

A European network activity is proposed on the novel states of matter in dilute quantum systems, that is ultracold atomic and molecular gases in magnetic and other traps. The programme builds on the synergy which was achieved in the ESF PESC Programme "BEC2000+ -- Bose-Einstein Condensation and beyond". The new programme adopts the current trends and developments of the field, which comprises degenerate Fermi gases, mixtures of Bose- and Fermi systems, homo- and heteronuclear molecular systems and even quantum phase transitions in the strongly interacting regime. Operational activities of the programme consist in the organization and support of conferences and workshops, a variety of visiting programmes, and a long-term fellowship programme for young researchers.

Keywords

Bose-Einstein condensation, quantum degenerate gases, superfluidity, atom optics

Status and Goals

The first observation of Bose-Einstein condensation in a dilute atomic gas of Rubidium in 1995 has initiated the development of a new branch of atomic, molecular, and optical (AMO) physics: the physics of ultracold atomic and molecular gases. This is an interdisciplinary research field which – besides touching diverse aspects of AMO physics – is now attracting growing attention from condensed matter physics, low temperature physics, statistical physics, chemical physics, and, more recently, the physics of quantum information.

The ESF, who was early aware of this development, launched a PESC Programme BEC2000+, which proved to be very stimulating for the European research on Bose-Einstein condensed systems. Building on the synergy already achieved, it is the aim of the QUDEDIS to further strengthen the created ties, to stimulate new collaborations, and to support the exploration of novel systems.

The European research on ultra cold gases is in direct competition with the excellent research of the US American AMO community. In this competition the European side achieved many breakthroughs in laboratories located in Austria, Great Britain, Finland, France, Germany, Italy and the Netherlands. At the beginning of 2003, the status of the field and the avenues of future research can be summarized as follows.

New trends in weakly interacting gases: Several major discoveries and seminal contributions have been done over the last four years, and European researches participating in the ESF BEC2000+ programme played a key role in these achievements. The most important of these involve

1. Generation and studies of vortices and superfluidity in Bose condensates (Cornell-Wieman, Dalibard, Foot, Stringari)

2. The link between BEC physics and nonlinear optics (Meystre, Phillips, Ketterle) and observations of dark and bright matter-wave solitons (Ertmer-Lewenstein, Phillips, Salomon)

3. The link between BEC physics and cosmology, in particular black hole physics (Leonhardt, Cirac)

4. Observation of condensation in new systems, such as Rubidium 85 (Cornell-Wieman), Potassium (Inguscio), metastable Helium (Aspect, Leduc), and Caesium (Grimm)

5. The exploration of routes towards the generation of molecular condensates via photoassociation and Feshbach resonances (Doyle, Heinzen, Cornell-Wieman, Javanainen, Pillet, Tiemann, Meier)

6. Cooling and manipulation of Fermi gases (Jin, Salomon, Inguscio, Weidemüller)

7. The research on cold dipolar gases (Shlyapnikov, Pfau, You, Rzazewski, Santos)

8. The investigation of routes towards superfluid BCS transition in Fermi gases (Baranov, Stoof, Zoller, Zwerger)

9. The studies of Fermi-Bose gaseous mixtures (Inguscio, Salomon).

Here the proposed network would provide the forum for a quick and frictionless exchange of techniques, tricks and methods with the ultimate goal to create the above named ultra cold systems using an easy-to-handle technology. The European collaborations and exchange

should allow the best European groups to maintain their leading position in the cold atom research and to compete efficiently with US, Japanese and Australian scientists.

Strongly interacting atomic and molecular gases: This new research field, where AMO meets condensed matter and statistical physics, studies different physical systems. It has been developing mainly theoretically in the last four years, but the first experiments have been already realized, and there are many experimental groups who plan to perform experiments in this area. The main lines of research involve:

1. Studies of one-dimensional bosonic (Tonks gas) and fermionic gases (Luttinger liquids), (Olshanii, Girardeau, Santos, Shlyapnikov, Stringari, Zoller)

2. Ultracold atomic and molecular gases in optical lattices, e.g. superfluid to Mott-insulator transition in cold lattice bosons (Experiment: Bloch-Hänsch, theory: Zoller, Cirac, Bruder, Santos-Lewenstein, Zwerger)

3. Experimental and theoretical studies of systems with very large scattering lengths (Wieman, Pethick)

4. The analysis of the resemblance between rapidly rotating bosonic gases and the fractional Quantum-Hall effect (Cirac,Zoller)

Here the purpose of the proposed programme would be to provide the basis for the necessary interdisciplinary training and collaboration between the well-established areas of condensed matter physics and the ongoing activities in the field of quantum degenerate atomic and molecular systems. Particularly important will be the transfer of theoretical methods of other research fields (such as exactly solvable quantum systems, quantum field theory and in particular conformal field theory, nuclear physics and physics of liquid Helium) to the physics of cold atomic and molecular gases. Also important will be the studies of possible applications of strongly interacting systems to quantum information or quantum chemistry.

Applications of degenerate ultracold gases:. In the recent years several ideas have been proposed which would employ atomic condensates in order to improve the precision in atom interferometry and frequency standards. Additionally ultra-cold gases in optical lattices have been suggested as good candidates for implementing quantum communication and computation schemes (Cirac, Zoller). Also atomic chips (Cornell, Hänsch, Schmiedmayer, Hinds, Zimmermann) and arrays of optical microtraps (Birkl-Ertmer) have been and are being developed, opening a rapidly-growing research field, namely the “atomics” (atom optics with miniaturized structures). The loading of a BEC into such structures opens fascinating questions regarding the loading itself, as well as the manipulation and detection of it. The purpose of the proposed network would be to stimulate developments in novel technological applications like nano-structuring, precision standards and real-time chemistry.

European Added Value

The area of cold quantum gases is one of the most rapidly developing areas of atomic, molecular and optical physics, and it has relevant overlaps with other important areas of physics, such as condensed matter or statistical physics. Currently, there are in Europe more than three hundred physicists with permanent positions working in this area, and more than four hundred PhD students. The fast dissemination of the latest results, the smooth exchange of new ideas and the interdisciplinary training and collaboration are necessary to uphold the current lead in the theoretical investigations and the experimental engagement on a competitive level. The European progress in fundamental research and the development of new technologies can only benefit from the QUDEDIS.

European Context

The QUDEDIS builds on the synergy already achieved in the PESC Program BEC2000+ which ends however in Dec 2003. One of the most successful instruments of integration and dissemination, the series of ESF Research Conferences "Bose-Einstein Condensation in Atomic Gases", which started Mont St. Odile 1995 (Chairman: Jook Walraven), and was continued Castelvecchio 1997 (Chairman: Martin Wilkens), San Feliu de Guixols 1999 (Chairman: Maciej Lewenstein), 2001 (Chairman: Ignacio Cirac) and 2003 (Chairman: Yvan Castin). The QUDEDIS plans to further support and sponsor this series of research conferences, which is now recognized to be the most important bi-annual event in the field.

The next important instrument, addressing the training of young researchers, which have been co-sponsored by the BEC2000+, are the Leiden study center and workshop 2000, the Trento study center and workshop in 2002, the Salerno workshop in 2001, the Lunteren conference in 2002, the Obergurgl workshop in 2003, the "Quantum Challenges" Symposium in Warsaw in 2003, and numerous other workshop of small and medium size. Here the QUDEDIS plans to continue the stimulation and support of such pan-European events.

With its new emphasis on the interdisciplinary character, which now includes – besides the atom- molecular and optics communities – the communities of the quantum information physics and computer sciences, condensed matter physics and even cosmology, the QUDEDIS will establish links to the corresponding ESF programmes, in particular the "COSLAB—Cosmology on the laboratory scale" (Co-chaired: Tom Kibble and Grigory Volovik), the potential follow-up of the VORTEX (Chairman: V.V. Moshchalkov), and the potential follow up of the QIT (Chairman: Martin Plenio). A first step in this direction is the first joint COSLAB – VORTEX - BEC200+ workshop in July 10-16th 2003 at the University of Basque Country, Bilbao, Spain.

The QUDEDIS will also synchronize its activities with the FP6 programmes of the European Union. Currently there exists a European RTN network which is devoted to the subject of quantum degenerate dilute gases, and which terminates in 2003. The QUDEDIS is already in contact with the potential follow-up EQM (Coordinator: Jacques Vigue) and other initiatives.

The QUDEDIS will also synchronise its activities with the national research programmes on the quantum degenerate dilute matter and related fields. At the time of writing this proposal, members of the QUDEDIS Steering Committee are actively involved in the following national research programmes

- Austria: FWF-SFB "Control and Measurement of Coherent Quantum Systems" (Coordinator: Peter Zoller)
- France: CNRS Programme "GDR Optique Atomique Integree et Nanostructures" (Coordinater: John Weiner, Toulose)

- Germany: DFG Priority Programme SPP1116 “Interactions in ultra cold atomic and molecular gases” (Coordinator: Martin Wilkens, Potsdam)

- Italy: INFM Research and Development Centre “Bose Einstein Condensation” Trento (Coordinator: Sandro Stringari, Trento)

- Netherlands: FOM Programme “Cold Atoms and Molecules” (Coordinator: Ben van Linden van den Heuvell, Amsterdam)

- Sweden: Carl Tryggers-Stiftelse Programme “Bose-Einstein Condensates – Cold Atoms for Quantum Manipulations and Quantum Information” (Coordinator: Anders Kastberg, Stockholm)

Programme Work Plan

The following operational activities are envisaged:

1. Application for and co-sponsoring of the ESF Research Conference Series “Bose-Einstein Condensation in Atomic Gases”. In the tradition of this series, which was already described above, the QUEDIDIS foresees two conferences to be held in fall 2005 and fall 2007.

2. Co-sponsoring or application, and organizing of small workshops, study centers and conferences, in particular in the years between the ESF conferences, that is in 2004 and 2006. Study centers should gather up to 30 participants for a 6-8 weeks and would have similar format as the Leiden study center 2000 and the Trento study center 2002. The accompanying workshops will gather up to 70 participants for 3-4 days. The other workshops which may be sponsored will have a format similar to the workshop “Quantum Challenges 2001” (Essen, September 2001) and “Quantum Challenges 2003” to be held in Warsaw in the fall of 2003.

3. Short term research visits between collaborating institutions on a transnational basis with particular attention to a “Theory visits Experiment” and “Experiment visits Experiment” exchange. Applications will be reviewed by the Chairman of the QUDEDIS who will forward his recommendations to the ESF office.

4. Fellowship program for young researchers, that is PhD students and junior PostDocs who want to work in young and less established groups. By default, support is on a 50 percent pitch-in basis for up to 6 month, yet full support may be granted in exceptional circumstances. The scheme is competitive. The program and a “Call for applications” will be announced. The applications will be reviewed by the QUDESDIS Steering Committee. Decisions of the Committee are forwarded to the ESF via the Chairman of the QUDEDIS.

5. Establish and maintain a Web-server which presents the European activities on the quantum degenerate dilute systems. The server should also mirror the established server at NIST, and it should become the standard link for related servers in other parts of the world. The Web-server will be installed and maintained by the chairman of the QUDEDIS.

6. An annual committee meeting in conjunction with an ESF conference or workshop. Activities of the committee include program organization of subsequent workshops and conferences, management of grants in the framework of the fellowship program for young researchers, and the review and preparation of an annual report to the PESC and ESF, respectively.

Program Budget and Duration

The program duration is 4 years from January 2004 to December 2007. The program budget derives from the envisaged operational activities as described above (all figures in kEuros)

Activity	2004	2005	2006	2007
Workshop	50	-	40	-
Conference	-	80	-	80
Fellowship	60	60	60	60
Short term	20	20	20	20
Coordinator	5	5	5	5
Total	125	165	125	165

Annex

Main Programme Proposers

Prof. Dr. Martin Wilkens
Institut für Physik, Universität Potsdam
Am Neuen Palais 10
D-14469 Potsdam
GERMANY
Tel: +49-331 977-1706/1628(Secr.)
Fax: +49-331 977-1767
e-mail: martin.wilkens@quantum.physik.uni-potsdam.de

Prof. Dr. Maciej Lewenstein
Institut für Theoretische Physik, Universität Hannover
Appelstr. 2
D-30167 Hannover
GERMANY
Tel: +49-511 762-5890/5889(Secr.)
Fax: +49-511 762-4945
e-mail: lewen@itp.uni-hannover.de

Short CV

Martin Wilkens , born 25 Sep 1956, graduated in 1983 from the University of Essen where he earned his Doctorate (Dr. rer. nat.) in 1987. Following his PostDoc years at the Center for Theoretical Physics in Warsaw, the Optical Sciences Center in Tucson, Arizona, and the Physics Department at the University of Konstanz, he was appointed full professor for theoretical physics at the University of Potsdam in 1997. His current research interests are in the physics of dilute quantum systems, the physics of quantum information and nano-optics. A list of 5 recent publications on the proposal theme:

1. "Atomic matter wave amplification by optical pumping" by U. Janicke and M. Wilkens, Adv. Atom. Mol. Opt. Phys. 4, 261 (1999);

2. "Heating of trapped atoms near thermal surfaces" by C. Henkel and M. Wilkens, Europhys. Lett. 47, 414 (1999);

3. "Transition temperature of the weakly interacting Bose gas: perturbative solution of the crossover equations in the canonical ensemble" by M. Wilkens, F. Illuminati and M. Krämer, J. Phys. B 33, L779 (2000);

4. "Phonon Spectrum and Dynamical Stability of a Dilute Quantum Degenerate Bose-Fermi Mixture" by H. Pu, W. Zhang, M. Wilkens, and P. Meystre, Phys. Rev. Lett. 88, 070408 (2002);

5. "Quantum field theory of dilute homogeneous Bose-Fermi mixtures at zero temperature: General formalism and beyond mean-field correction" by A.P. Albus, S.A. Gardiner, F. Illuminati, and M. Wilkens, Phys. Rev. A, 65, 053607 (2002).

Maciej Lewenstein, born 21 Sep 1955, graduated in 1979 from the Warsaw University and he earned his Doctorate (Dr. rer. nat.) from the University of Essen in 1983. Since 1980 till 1995 he was a staff member of the Centre for Theoretical Physics in Warsaw, where he has habilitated in 1986 and became a professor in 1993. He spent post doc and visiting fellow years in Essen, at Harvard, at JILA and in Saclay. In 1995 he was appointed a position in the Commissariat a l'Energie Atomique in Saclay, and in 1998 he moved to Hannover, where he is currently running the Theoretical Quantum Optics group. His current interest include physics of ultracold quantum gases, quantum information theory and ultrastrong laser-matter interactions.

1. S. Dettmer et al., Observation of Phase Fluctuations in Bose-Einstein Condensates, Phys. Rev. Lett. **87**, 160406 (2001).

2. P. Salieres et al., Feynman's path-integral approach for intense-laser-atom interactions, Science **292**, 902 (2001).

3. L. Santos, G. V. Shlyapnikov, P. Zoller, and M. Lewenstein, Bose-Einstein condensation of trapped dipolar gases, Phys. Rev. Lett. **85**, 1791 (2000).

4. K. Góral, L. Santos, and M. Lewenstein, Quantum phases of dipolar Bose gas in optical lattice, Phys. Rev. Lett. **88**, 170406 (2002)

5. A. Muryshev, G.V. Shlyapikov, W. Ertmer, K, Sengstock and M. Lewenstein, Dynamics of dark solitons in elongated Bose Einstein condensates, Phys. Rev. Lett. **89**, 110401 (2002).

Program Steering Committee

Prof. Dr. Peter Zoller, Institute for Theoretical Physics, University of Innsbruck
AUSTRIA

Prof. Dr. Klaus Mølmer, Inst. of Physics and Astronomy, Aarhus University, Aarhus
DENMARK

Prof. Dr. Simo Jaakkola, Department of Physics, University of Turku
FINLAND

Prof. Dr. Alain Aspect, Institute d'Optique, Université Paris Sud, Orsay
FRANCE

Prof. Dr. Gerd Rempe, Max-Planck Institut für Quantenoptik, Garching
GERMANY

Prof. Dr. Peter Szepfalusy, Institute for Solid State Physics, Eötvös Lorand University, Budapest
HUNGARY

Prof. Dr. Sandro Stringari, Department of Physics, University of Trento
ITALY

Prof. Dr. Wim Hogervorst, Dept. Natural Sciences, Free University of Amsterdam
THE NETHERLANDS

Prof. Dr. Kazimierz Rzazewski, Center for Theoretical Physics PAN, Warsaw
POLAND

Prof. Dr. Fernando Sols, Universidad Autonoma de Madrid
SPAIN

Prof. Dr. Stig Stenholm, Department of Physics, Technical University of Stockholm
SWEDEN

Prof. Dr. Christoph Bruder, University of Basel
SWITZERLAND

Prof. Dr. Keith Burnett, Clarendon Laboratory, University of Oxford
UNITED KINGDOM

Program Collaboration

AUSTRIA

Prof. Dr. Peter Zoller, Institute for Theoretical Physics, University of Innsbruck

Prof. Dr. Rudi Grimm, Institute for Experimental Physics, University of Innsbruck

DENMARK

Prof. Dr. Klaus Mølmer, Dept. of Physics and Astronomy, University of Aarhus, Aarhus

Prof. Dr. Chris Pethick, University of Copenhagen, Copenhagen

FINLAND

Prof. Dr. Simo Jaakkola, Department of Physics, University of Turku, Turku

Prof. Dr. Kalle-Antti Suominen, University of Turku, Turku

Prof. Dr. Päivi Törmä, University of Jyväskylä, Jyväskylä

FRANCE

Prof. Dr. Alain Aspect, Institut d'Optique, Université Paris Sud, Orsay

Dr. Yvan Castin, Laboratoire Kastler-Brossel, Ecole Normale Superieure, Paris

Prof. Dr. Jean Dalibard, Laboratoire Kastler-Brossel, Ecole Normale Superieure, Paris

Prof. C. Salomon, Laboratoire Kastler-Brossel, Ecole Normale Superieure, Paris

Dr. Jacques Vigue, LCAR, Universite Paul Sabatier Toulouse III, Toulouse

GERMANY

Prof. Dr. Wolfgang Ertmer, Institute for Quantum Optics, Universität Hannover

Prof. Dr. Theodor Hänsch, Max Planck Institute for Quantum Optics, Garching

Prof. Dr. Maciej Lewenstein, Institute for Theoretical Physics, Universität Hannover

Prof. Dr. Ignacio Cirac, Max Planck Institute for Quantum Optics, Garching

Prof. Dr. Hagen Kleinert, Freie Universität Berlin

Prof. Dr. Dieter Meschede, Institute for Applied Physics, Universität Bonn

Prof. G. Meijer, Fritz-Haber Institut, Berlin

Prof. Dr. Achim Peters, Humboldt Universität zu Berlin

Prof. Dr. Tilman Pfau, 5. Physikalisches Institut, Universität Stuttgart

Prof. Dr. Gerd Rempe, Max Planck Institute for Quantum Optics, Garching

Prof. Dr. Klaus Sengstock, Institut für Physik, Universität Hamburg

Prof. Dr. Martin Wilkens, Institut fuer Physik, Universität Potsdam

Prof. Dr. Claus Zimmermann, Institut für Physik, Universität Tübingen

Prof. Dr. Wilhelm Zwerger, Ludwig Maximilian Universität München

HUNGARY

Prof. Dr. Peter Szepfalusy, ISSP, Eötvös Lorand University, Budapest

ITALY

Prof. Dr. Ennio Arimondo, Department of Physics, University of Pisa

Prof. Dr. Fabrizio Illuminati, Department of Physics, University of Salerno

Prof. Dr. Massimo Inguscio, Department of Physics, University of Florence

Prof. Dr. Sandro Stringari, Department of Physics, University of Trento

THE NETHERLANDS

Prof. Dr. Wim Hogervorst, Dept. of Natural Sciences, Free University of Amsterdam

Prof. Dr. H. Stoof, Institute for Theoretical Physics, University of Utrecht, Utrecht

Prof. Dr. H. B. Van Linden von den Heuvell, University of Amsterdam

Prof. Dr. Jook Walraven, FOM Institute AMOLF, Amsterdam

Prof. Dr. Georgii V. Shlyapnikov, FOM Institute AMOLF, Amsterdam

POLAND

Prof. Dr. Kazimierz Rzazewski, Institute for Theoretical Physics PAN, Warsaw

Prof. Dr. Jakub Zakrzewski, Jagiellonian University, Cracow

SPAIN

Prof. Dr. Fernando Sols, Universidad Autonoma de Madrid

Dr. Luis Plaja, Universidad de Salamanca

SWEDEN

Prof. Dr. Stig Stenholm, Department of Physics, Technical University of Stockholm

SWITZERLAND

Prof. Dr. Christoph Bruder, University of Basel, Basel

Prof. Dr. Tilman Esslinger, ETH Zürich, Zürich

UNITED KINGDOM

Prof. Dr. Charles Adams, Department of Physics, Durham University

Prof. Dr. Keith Burnett, Clarendon Laboratory, University of Oxford

Prof. Dr. Edward Hinds, University of Sussex, Brighton

Prof. Dr. Ulf Leonhardt, University of St. Andrews

Other Applications

One of us (MW) is coordinating the ESF PESC Programme BEC2000+ which will terminate in 31. Dec. 2003.

Dr. J. Vigué, Toulouse, is coordinating a proposal for an European network of excellence “EQM - Engineering quantum matter”. This proposal is currently prepared within the 6th Framework Programme of the EU.

Dr. P. Verkerk, Lille, is coordinating a proposal for an European network “DYPEST – Dynamics in Periodic Structures”. This proposal is currently prepared within the 6th Framework Programme of the EU.

No further application on this or a similar topic has been proposed to the ESF.

No further application on this or a similar topic has been proposed to the COST Programme.