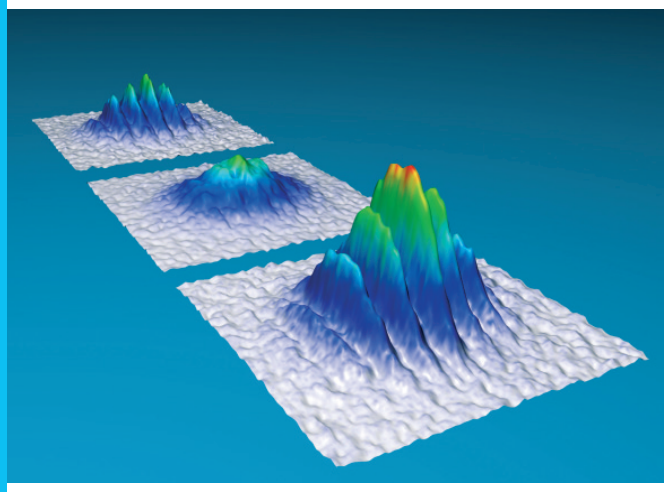
Quantum Degenerate Dilute Systems (QUDEDIS)

An ESF scientific programme

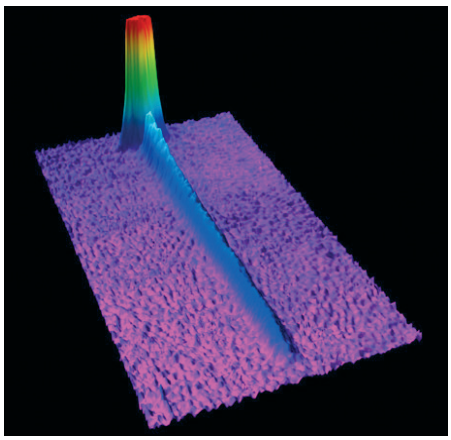


Quantum Degenerate Dilute Systems (QUDEDIS) is a European network activity on the novel states of matter in dilute quantum systems; that is ultracold atomic and molecular gases in magnetic and other traps. The programme adopts the current trends and developments of the field, which comprises degenerate Fermi gases, mixtures of Bose and Fermi systems, homo- and heteronuclear molecular systems and even quantum phase transitions in the strongly interacting regime.

The QUDEDIS programme provides 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.

Operational activities of the programme consist in the organisation and support of conferences and workshops, a variety of visiting programmes, and a long-term fellowship programme for young researchers.

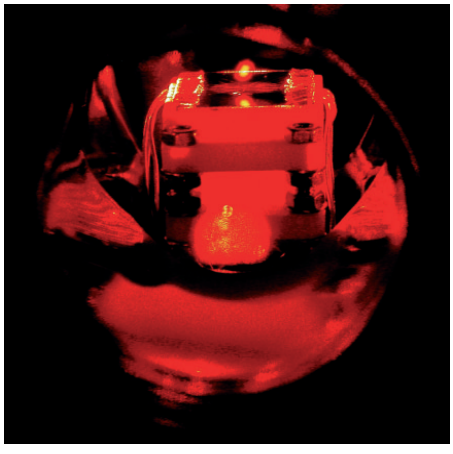
The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.



Three dimensional rendering of an Atom Laser beams emitted from a Bose-Einstein condensate. The higher the peak, the higher the density at this position. © I. Bloch, University of Mainz

Introduction

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.



Lithium atoms hoovering above the atom chip, cooled to be loaded into a microtrap. © J. Schmiedmayer, Physics Institute, University of Heidelberg

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 300 physicists with permanent positions and more than 400 PhD students working in this area. Rapid dissemination of the latest results, the smooth exchange of new ideas and interdisciplinary training and collaboration are necessary to maintain the current lead in theoretical investigations and experimental engagement at a competitive level.

With its new emphasis on interdisciplinarity, which now includes – besides the atom-molecular and optics communities – the communities of quantum information physics and computer sciences, condensed matter physics and even cosmology, the QUDEDIS programme will establish links to the corresponding ESF programmes and will also synchronise its activities with the Sixth Framework Programme of the European Union.

Altogether, QUDEDIS provides a forum for a fast and frictionless exchange of techniques and methods with the ultimate goal to create ultracold systems using an

easy-to-handle technology. European collaborations and exchanges should enable the best European groups to maintain their leading position in cold atom research and to compete efficiently with US, Japanese and Australian scientists.

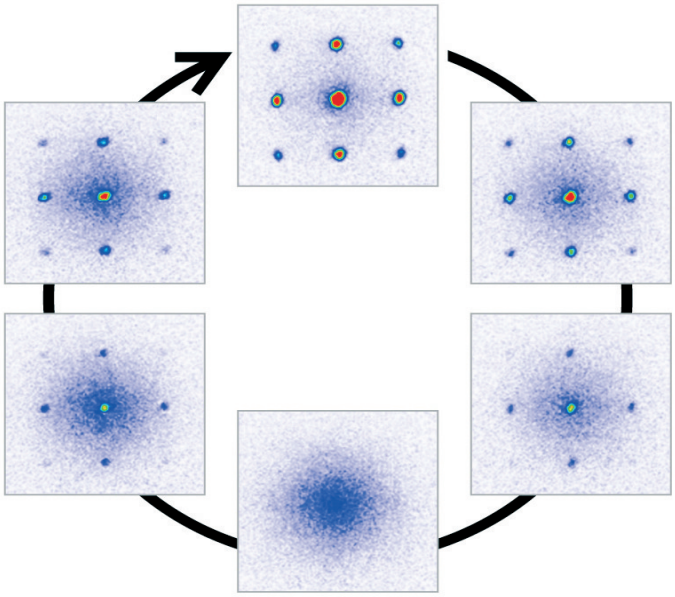
Scientific aims of QUDEDIS

The QUDEDIS programme provides 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. Studies of possible applications of strongly interacting systems to quantum information or quantum chemistry will also be important. The specific aims of QUDEDIS are as follows:

1. Weakly interacting gases

Several major discoveries and seminal contributions in the recent past have opened up highly interesting issues such as:

- generation and studies of vortices and superfluidity in Bose condensates
- observation of condensation in new systems, such as chromium and earth alkalines
- the exploration of routes towards the generation of molecular condensates via photo-association and Feshbach resonances
- cooling and manipulation of Fermi gases
- the investigation of routes towards superfluid BCS transition in Fermi gases and the studies of Fermi-Bose gaseous mixtures.

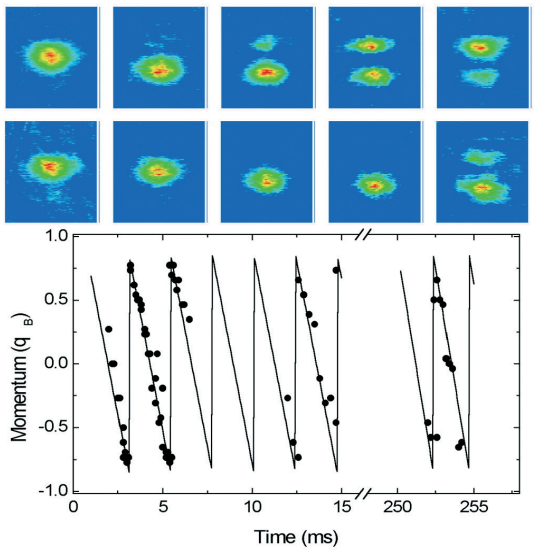


Collapse and revival. The images show absorption pictures of the interference of about 100,000 individual Bose-Einstein condensates. When there is a finite matter wave field, the individual BECs have a fixed phase relation and therefore form an interference pattern. At the time of the collapse, no interference is visible. © I. Bloch, University of Mainz

2. Strongly interacting atomic and molecular gases

This new research field has been developing mainly theoretically in the last four years, but the first experiments have already been realised, and there are many experimental groups who plan to perform experiments in this area. The main lines of research involve:

- studies of one-dimensional bosonic and fermionic gases (Luttinger liquids)
- ultracold atomic and molecular gases in optical lattices, e.g. superfluid to Mott-insulator transition in cold lattice bosons
- experimental and theoretical studies of systems with very large scattering lengths
- the analysis of the resemblance between rapidly rotating bosonic gases and the fractional quantum Hall effect.



Fermi degenerate gas of 40K performing Bloch oscillations in a vertical optical lattice.
© M. Inguscio, European Laboratory for Nonlinear Spectroscopy (LENS)

3. Applications of degenerate ultracold gases

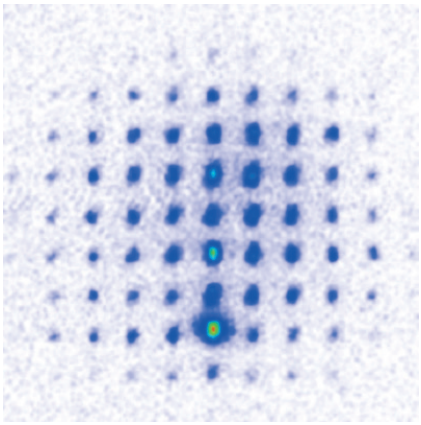
QUDEDIS strongly supports any activities which lead to the application of degenerate ultracold gases, such as:

- improving the precision in atom interferometry and frequency standards
- investigating the possibility of implementing ultracold gases in optical lattices for quantum communication and computation schemes
- developing atomic chips and arrays of optical microtraps
- loading a Bose-Einstein condensate into miniaturised structures and investigating its manipulation and detection.

QUDEDIS activities

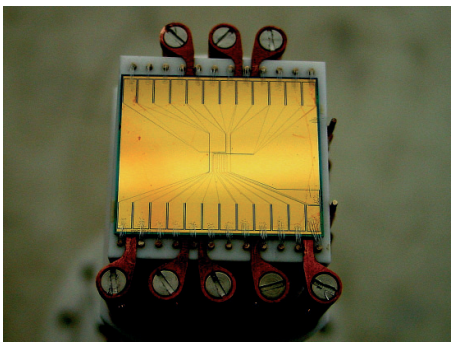
QUDEDIS will organise, co-sponsor or apply for the following activities.

- **ESF Research Conference Series** Bose-Einstein Condensation in Atomic Gases, to be held in autumn 2005 and autumn 2007.
- **Small workshops, study centres and conferences**, in particular in the years between the ESF conferences, that is in 2004 and 2006. Study centres should gather up to 30 participants for six to eight weeks and would have a format similar to the Leiden study centre 2000 and the Trento study centre 2002, which were co-sponsored by the ESF programme BEC2000+. The accompanying workshops should attract up to 70 participants for three to four days. Other workshops which may be sponsored will have a format similar to the workshop Quantum Challenges 2001 (Essen, September 2001) and Quantum Challenges 2003 (Warsaw, September 2003). Applications will be reviewed by the QUDEDIS Steering Committee who will forward its recommendation to the ESF Office and the Chair.



Phase Grating for Atoms. By pulsing on a 2D optical lattice for a very short time, the condensate is projected onto several momentum components. Almost 80 of these momentum components can be seen on this image.
© I. Bloch, University of Mainz

- **Short visit grants** 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 Chair of QUDEDIS who will forward his recommendations to the ESF office.
- **Exchange grants**, that is PhD students and junior postdocs who want to work in young and less established groups. By default, support is on a 50% pitch-in basis for up to six



Details of an atom chip used for mesoscopic BEC experiments. © J. Schmiedmayer, Physics Institute, University of Heidelberg

months, yet full support may be granted in exceptional circumstances. The scheme is competitive. The programme and a call for applications will be announced. The applications will be reviewed by the QUDEDIS Steering Committee. Decisions of the committee are forwarded to the ESF via the Chair of QUDEDIS.

- **Web-service** which presents the European activities on the quantum degenerate dilute systems (http://www.qudedis.org).
- **Annual steering committee meeting** in conjunction with an ESF conference or workshop. Activities of the committee include programme organisation of subsequent workshops and conferences, management of grants in the framework of the fellowship programme for young researchers, and the review and preparation of an annual report to ESF.

Funding

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For the latest information on this programme consult the *QUDEDIS* home page:
www.esf.org/qudedis

Cover picture:
Entanglement oscillations made visible through a matter wave interference pattern.
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