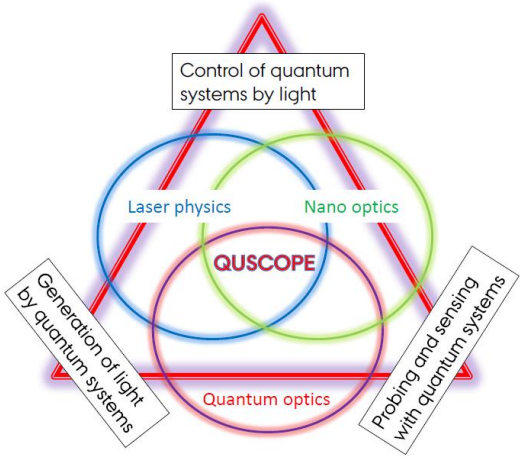
Villum Foundation Centre of Excellence

QUSCOPE



Annual report for 2014

Annual report for QUSCOPE, 2014

Introduction

By application from three research groups at the universities in Aarhus and Aalborg, the Villum Foundation provided a grant to establish the Villum Foundation Centre of Excellence, QUSCOPE, for the period 2014-2018. The purpose of the Centre of Excellence is to develop theory for optical processes in physical systems on the quantum scale.

The three central research themes of QUSCOPE are: *Quantum dynamics induced and controlled by light, generation of light by quantum systems* and *probing of quantum dynamics by light*. By combining the experience and insights in quantum optics, laser physics and nanooptics, developed in the three member teams in Aarhus and Aalborg, it is the ambition of QUSCOPE to provide more innovative proposals and more strongly founded analyses of the diverse physical and technological possibilities offered by modern laser and material technologies.

QUSCOPE has now been in operation for a year. We have recruited the first team members, and we have held several scientific activities. Many of our planned research projects are now running full steam, and the Centre has already obtained a wealth of results, which have already been published or submitted for publication.

Over the next few pages, we present a brief status of the recruitment, the activities, the budget, and the research of QUSCOPE.

We wish to draw attention to the QUSCOPE webpage, which we try to keep updated at all times with information about staff and students, activities in the Centre, publications etc.: http://phys.au.dk/forskning/forskningsomraader/quscope/.

Staff and students

We have decided to count all students and postdocs, contributing to the QUSCOPE research activities, as members of the Centre, and by the end of 2014, QUSCOPE consists of the three group leaders, Klaus Mølmer, Thomas Garm Pedersen and Lars Bojer Madsen, 7 postdocs and 13 PhD students. We furthermore dispose of part time assistance from a secretary and an IT-expert.

On the QUSCOPE Centre grant, we cover salaries and stipends for the following members (including already agreed employments starting in 2015):

Postdocs:

Juan Omiste,	August 2014-August 2015
Ralf Blattmann,	April 2015-April 2016
Mads Lund Trolle	Jan 2015-Jan 2016
Hector Mera	May 2015-May 2016

To massively strengthen the interdisciplinary activities between the research teams, we shall further advertise three two-year postdoc positions for employment in 2015 on (1) ultrafast/intense laser pulse interactions with mesoscopic systems, (2) description of atomic and molecular dynamics by quantum optical methods, and (3) matrix product state descriptions of optical phenomena in periodic structures.

PhD students:

Kenneth Hansen,	October 2014-October 2018
Chuan Yu,	October 2014-October 2017
Alexander Holm Kiilerich,	August 2014-August 2018
Eliska Greplova,	October 2014-October 2017
Farzad Bonabi	January 2015-January 2018
Jinglei Zhang*,	April 2015-April 2018

*: pending on her admittance to the Graduate School of Science in Aarhus.

The remaining three PhD students planned in our research proposal will also be employed in 2015.

QUSCOPE Centre Events.

The Centre hosts a number of events of relevance to the students and post docs.

We have now held 2 workshop retreats with participation of all QUSCOPE members, and with the new postdocs and PhD students, we expect to intensify the corporation between the groups and the generation of new interdisciplinary ideas.

2015

January 29-30	Retreat for the full QUSCOPE Centre to Bramslev Gaard (program)
January	PhD course in Aalborg on "Nonlinear nano-optics"

2014

December 11	Scientific Meeting for all members of QUSCOPE in Aarhus
November 18	Invited talk by Daniel Reich, University of Kassel, Germany, *Efficient Characterization and Optimal Control of Open Quantum Systems*
October 13	Invited talk by Ralf Blattmann, University of Augsburg, Germany, *Qubit interference at avoided crossings: The role of driving shape and bath coupling*
August 14-15	Retreat for the full QUSCOPE Centre to Bramslev Gaard (program, photos)
June 13	Invited talk by Antoine Browaeys, Institut d'Optique, Palaiseau, France, *Experimental investigations of resonant dipole-dipole interaction between cold atoms*
June 12	Invited talk by Erika Andersson, Heriot-Watt University, Edinburgh, Scotland, *Quantum digital signatures*
March 12	Invited talk by Juan José Omiste, Department of Atomic, Molecular and Nuclear Physics, University of Granada, Spain, *Controlling the rotational dynamics of molecules using combined laser pulses and static electric fields* (abstract)

Economy

Please find below a copy from the official University accounting system, providing the key figures (DKK) for the QUSCOPE spending in 2014.

Projekt 16437 (AU+AAU):	Forbrug 2014	Budget 2014	Rest
Salary Postdoc	207.683,45	1.689.000,00	1.481.316,55
Salary PHD	263.053,72	1.250.000,66	986.946,94
Salary TAP support	392.054,97	401.693,00	9.638,03
Running costs	318.366,83	559.999,34	241.632,51
Equipment	500.000,00	609.000,00	109.000,00
I ALT	**1.681.158,97**	**4.509.693,00**	**2.828.534,03**

Comments: Primary expenses are salaries and stipends, and since recruitment only began in 2014, our expenses have been delayed compared to the budget. This delay was unavoidable, but as we employ the planned number of students and postdocs we will bring our expenses in agreement with the total budget. The equipment cost primarily covers a cluster computer system, which has been installed and which will be an important resource for the entire duration of the Centre.

Research

QUSCOPE has initiated a number of projects. We present here a brief summary of our results obtained in 2014, organized by the research themes (numbers refer to the list of publication in the end of the report).

Theme A: Quantum dynamics induced and controlled by light

We have shown how to use laser light to induce long range binding between atoms and prepare entanglement and quantum computing gate operations (6). We have further shown how atomic decay can be steered to drive ensembles of atoms into entangled excited states – useful for communication, computing and precision sensing purposes (1).

With the proposal of technological applications of quantum phenomena a need to verify that a quantum system behaves ideally as described by theory arises. We have developed quantum state and process tomographic tools, and we have used these tools to determine the resilience of different state preparation and quantum gate protocols to experimental error sources (20).

Theme B: Generation of light by quantum systems

We have started non-perturbative studies of electrical fields in atoms and condensed matter systems. Hence, we have analyzed the effect of electrostatic fields on energies and tunneling processed in atoms with emphasis on “resummation” of divergent

mathematical sums (21). In addition, we have studied the effect of electrostatic fields on the optical properties of solids both with and without interactions between electrons. This has led to analytical results for simple systems in one spatial dimension (24). Several other quantum based investigations have been carried out for edge doping in graphene (22), bilayer graphene antidot lattices (23), and the magnetization of free-standing and graphene-embedded iron membranes (25).

The new theory 'time-dependent restricted active-space self-consistent-field' (TD-RASSCF) has been developed and described. Calculations of high-order harmonic generation (HHG) in reduced dimensions have been described, and the computational scaling has been discussed (10).

Furthermore the new theory 'time-dependent generalized-active-space configuration-interaction' (TD-GASCI) has been implemented and discussed (2).

Theme C: Probing of quantum dynamics by light

It has been studied how a field-induced many-electron potential affects the photoelectron angular distribution in naphthalene molecules. This potential has been shown to facilitate the creation of electrons with very low energy. The effect depends on the instantaneous value of the induced dipole. The results reported therefore pave the way for studies of ultrafast intramolecular transformations by using combinations of pump and probe pulses (7).

Quantum computers are intended to solve hard problems, and therefore it is intrinsically difficult to check if they behave correctly according to theory. We have assessed a particular problem – boson sampling – and derived tests that validate with high fidelity the proper functioning of devices (5). The tests can be implemented with light beams and with atoms.

We have developed new theoretical approaches to precision probing of physical quantities through their influence on microscopic quantum systems. While measurements on quantum systems are subject to fundamental uncertainties, they also influence the system in a manner that makes them more sensitive, and we have shown that proper statistical analyses of signal fluctuations yield orders of magnitude more precision than conventional use of the average signals (12,17). A QUSCOPE result concerning fundamental theoretical resolution limits has been nominated "Editor's Suggestion" in the Physical Review Letters (16).

Publications

2014

1. D. D. Bhaktavatsala Rao and Klaus Mølmer, Deterministic entanglement of Rydberg ensembles by engineered dissipation, Phys. Rev. A **90**, 062319 (2014).
2. S. Bauch, L. K. Sørensen, and L. B. Madsen, Time-dependent generalized-active-space configuration-interaction approach to photoionization dynamics of atoms and molecules, Phys. Rev. A **90**, 062508 (2014).
3. Lun Yue and Lars Bojer Madsen, Dissociative ionization of H_2^+ using intense femtosecond XUV laser pulses, Phys. Rev. A **90**, 063408 (2014).

4. Hamed Saberi, Tomáš Opatrný, Klaus Mølmer, and Adolfo del Campo, Adiabatic tracking of quantum many-body dynamics, Phys. Rev. A **90**, 060301(R) (2014).
5. Malte C. Tichy and Christian Kraglund Andersen, Comment on "Contextuality in Bosonic Bunching", Phys. Rev. Lett. **113**, 138901 (2014).
6. David Petrosyan and Klaus Mølmer, Binding Potentials and Interaction Gates between Microwave-Dressed Rydberg Atoms, Phys. Rev. Lett. **113**, 123003 (2014).
7. D. Dimitrovski, J. Maurer, H. Stapelfeldt, and L. B. Madsen, Low-Energy Photoelectrons in Strong-Field Ionization by Laser Pulses with Large Ellipticity, Phys.Rev.Lett. **113**, 103005 (2014).
8. Klaus Mølmer, Quantum memory: Needle in a haystack, Nature Physics **10**, 707–708 | news & views (2014).
9. Lauge Christensen, Jens H. Nielsen, Christian B. Brandt, Christian B. Madsen, Lars Bojer Madsen, Craig S. Slater, Alexandra Lauer, Mark Brouard, Mikael P. Johansson, Benjamin Shepperson, and Henrik Stapelfeldt, Dynamic Stark Control of Torsional Motion by a Pair of Laser Pulses, Phys. Rev. Lett. **113**, 073005 (2014).
10. Haruhide Miyagi and Lars Bojer Madsen, Time-dependent restricted-active-space self-consistent-field theory for laser-driven many-electron dynamics. II. Extended formulation and numerical analysis, Phys. Rev. A **89**, 063416 (pages 15) (2014).
11. Malte C. Tichy, Klaus Mayer, Andreas Buchleitner, and Klaus Mølmer, Stringent and Efficient Assessment of Boson-Sampling Devices, Phys. Rev. Lett. **113**, 020502 (2014).
12. Alexander Holm Kiilerich and Klaus Mølmer, Estimation of atomic interaction parameters by photon counting, Phys. Rev. A **89**, 052110 (2014).
13. P. Haikka and K. Mølmer, Dissipative Landau-Zener level crossing subject to continuous measurement: Excitation despite decay, Phys. Rev. A **89**, 052114 (2014).

2015

14. Christian Kraglund Andersen and Klaus Mølmer, Circuit QED Flip-Flop Memory with All-Microwave Switching, Phys. Rev. Applied **3**, 024002 (2015).
15. Malte C. Tichy, Young-Sik Ra, Hyang-Tag Lim, Clemens Gneiting, Yoon-Ho Kim and Klaus Mølmer, Double-Fock superposition interferometry for differential diagnosis of decoherence, New J. Phys. **17** 023008 (2015).
16. Klaus Mølmer, Hypothesis Testing with Open Quantum Systems, Phys. Rev. Lett. **114**, 040401 (2015) (Editor's Suggestion).
17. Alexander Holm Kiilerich and Klaus Mølmer, Parameter estimation by multichannel photon counting, Phys. Rev. A **91**, 012119 (2015).
18. Jens Svensmark, Oleg I. Tolstikhin, and Lars Bojer Madsen, Coulomb and dipole effects in tunneling ionization of molecules including nuclear motion, Phys. Rev. A **91**, 013408 (2015).
19. John J. L. Morton and Klaus Mølmer, Quantum information: Spin memories in for the long haul, Nature **517** 153–154| news & views (2015).
20. J. Gulliksen, D. D. Bhaktavatsala Rao and K. Mølmer, Characterization of how dissipation and dephasing errors accumulate in quantum computers; *EPJ Quantum Technology*, **2**:4 (2015).

Submitted

21. H. Mera, T. Garm Pedersen, and B.K. Nikolic, "Nonperturbative quantum physics from low-order perturbation theory", submitted for publication.
22. T. Garm Pedersen, "Self-consistent model of edge doping in graphene", submitted.
23. R. Petersen and T. Garm Pedersen, "Bandgap scaling in bilayer graphene antidot lattices", submitted for publication.
24. T. Garm Pedersen, "Optical response of one dimensional semiconductors", submitted.
25. M. Thomsen, S.J. Brun, and T. Garm Pedersen, "Stability and magnetization of free-standing and graphene-embedded iron membranes", submitted for publication.
26. S.J. Brun and T. Garm Pedersen, "Intense and tunable second-harmonic generation in biased bilayer graphene", submitted for publication.
27. David Petrosyan, D. D. Bhaktavatsala Rao and Klaus Mølmer, Filtering single atoms from Rydberg blockaded mesoscopic ensembles, submitted for publication; arXiv:1501.05165
28. Théo Rybarczyk, Stefan Gerlich, Bruno Peaudecerf, Mariane Penasa, Brian Julsgaard, Klaus Moelmer, Sébastien Gleyzes, Michel Brune , Jean-Michel Raimond, Serge Haroche, Igor Dotsenko, Past quantum state analysis of the photon number evolution in a cavity; submitted for publication; arxiv.org/abs/1409.0958
29. Christian Kraglund Andersen and Klaus Mølmer, Multi-frequency modes in superconducting resonators: Bridging frequency gaps in off-resonant couplings; submitted for publication; arXiv:1410.6644
30. D. Tan, S. Weber, I. Siddiqi, K. Mølmer, K. W. Murch, Prediction and retrodiction for a continuously monitored superconducting qubit; accepted for publication; arXiv:1409.0510.
31. N. I. Shvetsov-Shilovski, L. B. Madsen, and E. Räsänen, Suppression of strong-field ionization by optimal pulse shaping: Application to hydrogen and the hydrogen molecular ion, submitted for publication.
32. D. Dimitrovski and L.B. Madsen, Theory of low-energy photoelectrons in strong-field ionization by laser pulses with large ellipticity, submitted for publication.
33. P. M. Kraus, O. I. Tolstikhin, D. Baykusheva, A. Rupenyan, J. Schneider, C. Z. Bisgaard, T. Morishita, F. Jensen, L. B. Madsen, and H. J. Wörner, Observation of laser-induced electronic structure in oriented polyatomic molecules, submitted for publication.