



ERC-Starting Grants 2007 – QIPC project fact sheets

Introduction

Over 70 projects have been submitted on Quantum Information in the mathematics, physics, chemistry, computer science and engineering panels. These specific panels received 3669 proposals in total.

The granting process is ongoing as of today (5/3/08). Circa 275 projects (grand total over all domains of natural sciences and engineering, social sciences and humanities, life sciences) will receive an ERC Starting Grant. 5 of them are projects in the field of Quantum Information Processing and Communication:

Panel	Title	Principal Investigator
Fundamental constituents of matter	Experimental Linear Optics Quantum Information Processing with Atoms and Photons	Jian-Wei Pan, Univ. of Heidelberg
	Quantum gases of ultracold polar molecules	Giovanni Modugno, LENS, Firenze
Condensed matter in physics and chemistry	Control of entangled electron spins on a chip	Lieven Vandersypen, TU Delft
	Coherence of Spins in Semiconductor Nanostructures	Dominik Zumbühl, Univ. of Bazel
Information and communication	The power of quantum computers	Julia Kempe, Tel Aviv University

Experimental Linear Optics Quantum Information Processing with Atoms and Photons
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Acronym: AtomPhotonLOQIP

Principal investigator: Jian-Wei Pan (jian-wei.pan@physi.uni-heidelberg.de)

Host institute: Physikalisches Institut, Universität Heidelberg

Duration: 60 months

Quantum information science and atom optics are among the most active fields in modern physics. In recent years, many theoretical efforts have been made to combine these two fields. Recent experimental progresses have shown the in-principle possibility to perform scalable quantum information processing (QIP) with linear optics and atomic ensembles. The main purpose of the present project is to use atomic qubits as quantum memory and exploit photonic qubits for information transfer and processing to achieve efficient linear optics QIP. On the one hand, utilizing the interaction between laser pulses and atomic ensembles we will experimentally investigate the potentials of atomic ensembles in the gas phase to build quantum repeaters for long-distance quantum communication, that is, to develop a new technological solution for quantum repeaters making use of the effective qubit-type entanglement of two cold atomic ensembles by a projective measurement of individual photons by spontaneous Raman processes. On this basis, we will further investigate the advantages of cold atoms in an optical trap to enhance the coherence time of atomic qubits beyond the threshold for scalable realization of quantum repeaters. Moreover, building on our long experience in research on multi-photon entanglement, we also plan to perform a number of significant experiments in the field of QIP with particular emphasis on fault-tolerant quantum computation, photon-loss-tolerant quantum computation and cluster-state based quantum simulation. Finally, by combining the techniques developed in the above quantum memory and multi-photon interference experiments, we will further experimentally investigate the possibility to achieve quantum teleportation between photonic and atomic qubits, quantum teleportation between remote atomic qubits and efficient entanglement generation via classical feed-forward. The techniques that will be developed in the present project will lay the basis for future large scale realizations of linear optical QIP with atoms and photons.

Quantum gases of ultracold polar molecules

Acronym: QUPOL

Principal investigator: Giovanni Modugno (modugno@lens.unifi.it)

Host institute: European Laboratory for Nonlinear Spectroscopy (LENS), Firenze

Duration: 60 months

I propose to realize quantum gases of ultracold molecules with a permanent electric dipole moment. This project aims at a significant extension of the field of ultracold quantum gases towards more complex particles interacting via long-range, anisotropic interactions. Quantum gases of polar molecules would allow to study novel kinds of matter waves, to solve open questions in modern condensed matter physics, to explore novel quantum phases and to implement novel quantum computing schemes. Weakly bound heteronuclear dimers formed in ultracold atomic quantum mixtures via magnetic Feshbach resonances will be coherently transferred to deeply-bound ro-vibrational states using laser fields. The formation of both bosonic and fermionic molecules will be explored in different alkali mixtures. The high degree of coherence of the molecular quantum gases will allow to prepare them in selected rotational states of the absolute ground electronic and vibrational state. The molecular electric dipoles will be manipulated via electric and microwave fields. The precise dynamical control of the shape and strength of the dipole-dipole potential will allow to engineer a variety of quantum states and to study many interdisciplinary phenomena. The following themes will be explored: phenomenology of dipolar quantum gases, lattice spin models, polar molecules as qubits.

Control of entangled electron spins on a chip

Acronym: CEESC

Principal investigator: Lieven Vandersypen (l.m.k.vandersypen@tudelft.nl)

Host institute: Kavli Institute of NanoScience, University of Technology, Delft

Duration: 60 months

The promise of nanoscience stems from the fundamentally new behavior that emerges at the nanoscale. Here, we propose to explore, control and exploit one of the most dramatic aspects of this unusual behavior: quantum entanglement of spins. Our nanoscale system of choice is an array of semiconductor quantum dots that each contain one single electron. Thanks to a string of recent breakthroughs, it is now possible to initialize, coherently manipulate and read out the spin state of one such electron, and to couple it coherently to a spin in a neighboring dot. Today, we are at the brink of a new era in this field, in which entanglement will play the central part. The primary goal of this proposal, therefore, is to experimentally demonstrate that electron spins in quantum dots can really be entangled, and to control this entanglement in time. We will then use this capability to implement various quantum information protocols such as quantum algorithms and teleportation, which intrinsically rely on entanglement to realize tasks that are classically impossible. In order to push the level of coherent control to its limits, we will suppress fluctuations in the normally uncontrolled spin environment, and pursue novel quantum dot technologies which offer an intrinsically 'quiet' environment. Our long-term dream is to demonstrate that the accuracy threshold for fault-tolerant quantum computation can be reached in this system, which would permit quantum coherence and entanglement to be preserved indefinitely. This research is presently very much at the stage of exploratory research and is bound to produce surprising and unexpected outcomes. Furthermore, we are convinced that pushing the frontier of quantum control in nanoscale devices has a real potential to lead to future quantum technologies.

Acronym: COSPSENA

Principal investigator: Dominik Zumbühl (dominik.zumbuhl@unibas.ch)

Host institute: Department of Physics, University of Basel

Duration: 60 months

Macroscopic control of quantum states is a major theme in much of modern physics because quantum coherence enables study of fundamental physics and has promising applications for quantum information processing. The potential significance of quantum computing is now recognized well beyond the physics community. For electron spins in GaAs quantum dots, it has become clear that decoherence caused by interactions with the nuclear spins is a major challenge. We propose to investigate and reduce hyperfine induced decoherence with two complementary approaches: nuclear spin state narrowing and nuclear spin polarization. We propose a new projective state narrowing technique: a large, Coulomb blockaded dot measures the qubit nuclear ensemble, resulting in enhanced spin coherence times. Further, mediated by an interacting 2D electron gas via hyperfine interaction, a low temperature nuclear ferromagnetic spin state was predicted, which we propose to investigate using a quantum point contact as a nuclear polarization detector. Estimates indicate that the nuclear ferromagnetic transition occurs in the sub-Millikelvin range, well below already hard to reach temperatures around 10 mK. However, the exciting combination of interacting electron and nuclear spin physics as well as applications in spin qubits give ample incentive to strive for sub-Millikelvin temperatures in nanostructures. We propose to build a novel type of nuclear demagnetization refrigerator aiming to reach electron temperatures of 0.1 mK in semiconductor nanostructures. This interdisciplinary project combines Microkelvin and nanophysics, going well beyond the status quo. It is a challenging project that could be the beginning of a new era of coherent spin physics with unprecedented quantum control. This project requires a several year commitment and a team of three graduate students plus one postdoctoral fellow.

Acronym: QUCO

Principal investigator: Julia Kempe (kempe@cs.tau.ac.il)

Host institute: Tel Aviv University

Duration: 60 months

Quantum computation has been put forward as a way to overcome current computational limits, by exploiting the quantum properties of nature. It is an interdisciplinary area at the interface of physics and computation. Since Shor's groundbreaking discovery in 1994 that a quantum computer can factor numbers efficiently, strong, steady advances have been made in understanding the advantages of quantum resources and numerous experimental efforts are underway to implement this model of computation. Our research goal is to expand our understanding of quantum resources and computation and its interplay with classical computation, as well as to open new directions. More specifically, we want to advance progress in algorithm design, using new paradigms we have recently helped to develop, and to deepen our understanding of the computational power of physical resources like shared quantum states (entanglement), quantum communication, quantum memory and restricted quantum systems. An important aspect of this proposal is to parallel this investigation into the power of quantum systems with a study of its limits. Specifically we want to identify potential hard problems for quantum computers and to explore their hardness properties as a base for new classical cryptosystems that are secure against quantum adversaries. We also want to deepen our understanding of the effects of an adversary with quantum resources in cryptography. In a society where information is a crucial economic resource it is important to protect today's information against tomorrow's possible progress in the implementation of quantum computers. In this line of research we also propose to explore the systematic use of the emerging toolbox of quantum techniques to find solutions for classical problems with quantum arguments.