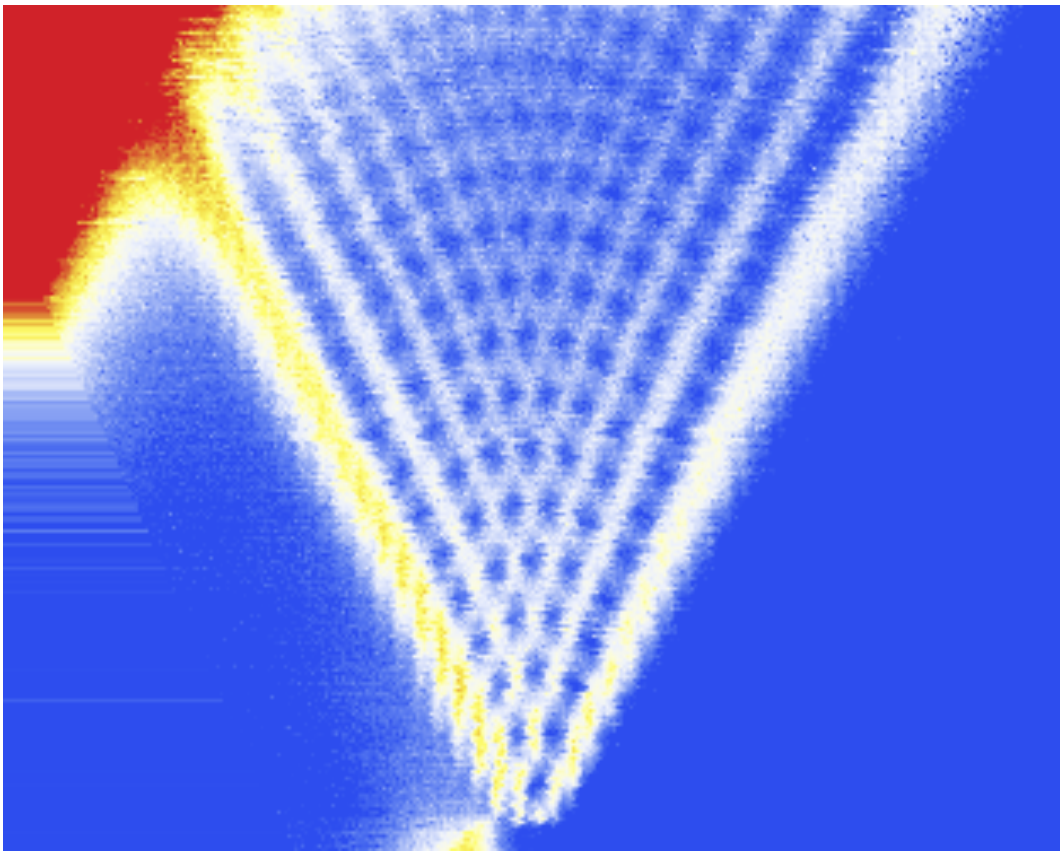
ICTP – Eurasian Centre for Advanced Research

Advanced Workshop on Landau-Zener Interferometry and Quantum Control in Condensed Matter

Abstract Book



29 September - 3 October 2014, İzmir, Turkey

Preface

The ICTP - Eurasian Centre for Advanced Research (ICTP-ECAR), Center for NanoScience (CeNS, Munich, Germany) and Nanosystems Initiative Munich (NIM, Munich, Germany) are organizing the Advanced Workshop on Landau - Zener Interferometry and Quantum Control in Condensed Matter, at ICTP-ECAR Centre, IZTECH, Izmir (Turkey), from 29th September to 3rd October 2014.

The workshop will address recent developments on Landau-Zener dynamics and related quantum control in complex systems including (but not limited to) many-body effects in ultracold gases, dissipative Landau-Zener transitions, Landau-Zener interferometry in superconducting qubits, double and triple quantum dots, spin & charge qubits, N-V centers and nano-mechanical systems.

The central idea of this workshop is to bring together various condensed matter communities, dealing with complex systems, where the nonequilibrium dynamics at avoided crossings is (other than in pure atomic systems) highly influenced by many-body interactions and, in many cases, environmental fluctuations. We have about 80 participants including 26 invited talks and 16 poster presentations given by the world experts in order to exchange ideas and shape new links beyond the traditional community boundaries. We hope to facilitate Landau-Zener interferometry and quantum control as one of the key spectroscopic tools in condensed matter systems for the future.

Organizing Committee

About ICTP-ECAR

ICTP-Eurasian Centre for Advanced Research (ICTP–ECAR) is a new regional centre intended to foster the advancement of basic sciences in Eastern Europe and Near Asia (in particular, Balkan, Black Sea, Inner Asia, Middle East and Northern Africa) countries. The Centre's organization and activities are based on the decades-long successful model of ICTP (www.ictp.it). ICTP-ECAR is located in the campus of Izmir Institute of Technology, Izmir, Turkey.

The ICTP – ECAR's goals are:

- Conduct scientific research at the highest international standards.
- Provide an international meeting basis for the scientists of the region and the world through schools, workshops and visiting programs.
- Support research in those Eurasian countries where scientific research is not yet well-developed.

Please visit http://www.ictp-ecar.org for further information about the ICTP-ECAR.

ORAL PRESENTATIONS

Sweep a Qubit to Entangle States and to Gauge its Environment

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Abstract

Here, we shall demonstrate that the sweep of a Qubit which is coupled to external quantum degrees of freedom (such as quantum oscillator degrees of freedom) is extremely beneficial for entanglement creation and the gauging of quantum dissipation. Recently, we succeeded in the derivation of the *excact zero-temperature transition probability for the dissipative Landau-Zener problem* [1]. The standard, i.e. the non-dissipative Landau-Zener problem, is an exactly solvable textbook example in time-dependent quantum mechanics, having found its way into many applications in physics and chemistry. Our exact result [1] constitutes an prominent generalization: It describes how the coupling of the Qubit to its environment impacts the transition probability. The measurement of this transition probability allows then for a precise gauging of the quantum-dissipation at work. Moreover, we find that the final quantum state exhibits a peculiar entanglement between the Qubit and the coupled quantum oscillator degrees [2]. It is possible to selectively perform a multi-partite entanglement among different oscillator degrees of freedom [3], -- including an entanglement with a whole bath [1, 4]. A large class of realistic types of coupling is considered. Surprisingly, the final transition probability is not affected at all by environments that only cause pure dephasing. In general, we find that Landau-Zener sweeps provide a robust tool for characterizing the environment of a tunable Qubit. Promising applications include superconducting Qubits, especially in circuit- QED [2,3,4,5].

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Quantum Simulations of Condensed Matter and Exotic Phenomena with Strongly Correlated Photons and Polaritons

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(1) School of Electronic and Computer Engineering, Technical University of Crete

(2) Centre for Quantum Technologies, National University of Singapore

Abstract

I will start by briefly reviewing our early works for observing photon-blockade induced Mott transitions and the photonic Fractional Hall effect in coupled cavity QED systems[1]. I will continue by analyzing our more recent proposals in realizing classical and relativistic interacting 1D models using slow light and describe the basics idea behind the photonic Luttinger liquid and the Thirring model in nonlinear optical set ups exhibiting strong photon nonlinearities [2]. I will continue with our recent efforts for simulations of out of equilibrium and topological models in driven systems[3,4,5] and conclude by presenting in more detail a recent experimental implementation in simulating the unphysical Majorana equation and charge conjugation dynamics using photons in an integrated photonic chip [6].

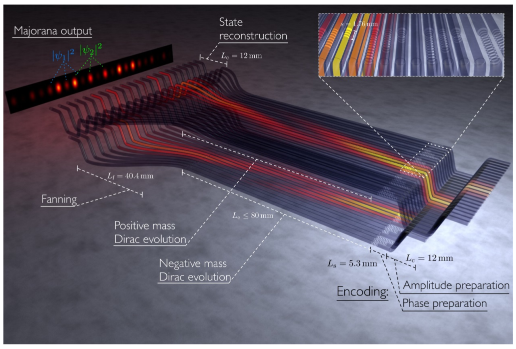

Figure 1. *Experimental simulation of charge conservation violation and Majorana dynamics", arXiv:1404.5444*

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Coherent Landau-Zener Transitions in Superconducting Qubits: Interferometry, Spectroscopy, Cooling, and Control

William D. Oliver [1]

1. MIT, USA

Abstract:

Superconducting persistent-current qubits are quantum-coherent artificial atoms with multiple energy levels. In the presence of large-amplitude driving fields, the qubit state can be swept through one or more energy-level avoided crossings. The resulting Landau-Zener-Stueckelberg (LZS) transitions mediate quantum-coherent phenomena with application to qubit characterization, control, and state-preparation methods for quantum information science and technology applications.

In this talk, we present several examples of LZS-mediated quantum coherence in a strongly-driven niobium persistent-current flux qubit. The first is Stueckelberg interferometry [1], by which we observed quantum interference fringes in the transition rates for n-photon transitions, with n as large as 50. The second is microwave-induced cooling [2], by which we achieved effective qubit temperatures < 3 mK, a factor 10x-100x lower than the dilution refrigerator ambient temperature. The third is amplitude spectroscopy [3], a technique that monitors the system response to amplitude rather than frequency. This allowed us to probe the energy spectra of our artificial atom from 0.01 – 120 GHz, while driving it at a fixed frequency 0.16 GHz. The last example is an emulation of universal conductance fluctuations as mediated by LZS transitions [4].

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Characterization of Qubit Dephasing by Landau-Zener-Stückelberg-Majorana Interferometry

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5. Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

Abstract

Driving a quantum mechanical two-level system (a qubit) through its avoided crossing can result in non-trivial dynamics, especially at the transition between adiabatic and non-adiabatic driving, a famous example being the Landau-Zener transition [1]. We use Landau-Zener transitions to split a single electron in two wave packets just as a photon can be split by an optical beam splitter. The two wave packets residing at different energies acquire a phase difference in time. Landau-Zener-Stückelberg-Majorana (LZSM) interferometry [2] is based on periodically driving the qubit through its avoided crossing. The phase difference of the two wave packets acquired between subsequent crossings results in a characteristic interference pattern in the occupation difference of the qubit states. We use a complete Floquet-based Redfield theory [3] to describe the dynamics of our driven charge qubit and we demonstrate that LZSM interferometry is a straight forward method to characterize qubits and their coupling to a complex environment. In our case, we implement a two-electron charge qubit in a GaAs-based lateral double quantum dot and measure the single electron tunneling current through the system in a wide temperature range between 20 and 400 mK. The temperature dependent interference patterns grant access to the all relevant qubit properties including the qubit's coherence time (T2 ~ 200 ns) and the nature of the noisy environment of our solid state system where the electron-phonon interaction is the dominant mechanism of relaxation and decoherence [4].

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Landau-Zener-Stückelberg Interferometry: A Tool for Measuring Decoherence

Sigmund Kohler[1]

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Abstract

Double quantum dots with long coherence times allow the implementation of coherent tunnel phenomena. For instance, if an energy level of one dot is swept such that it crosses a level of the other dot, one observes Landau-Zener transitions. Repeated sweeps lead to the so-called Landau-Zener-Stückelberg interference visible in a characteristic pattern as a function of the detuning and the amplitude of the sweeps. The experimentally observed fading of this interference pattern with increasing temperature is explained in terms of a transport calculation for which a coupling to bulk phonons causes decoherence. The comparison with experimental data allows us to determine the parameters of the system-bath model and to draw conclusions about the coherence time of charge qubits implemented with double quantum dots [1].
Changing the shape of the driving field from a pure cosine to an arbitrary periodic function has only a minor influence on the interference pattern as a function of the amplitude and the detuning. By contrast, the shape of the driving leaves its fingerprints in the Fourier transformed of the pattern. We determine ithe generic structure and the symmetries of the latter. Analytical results are confirmed by a numerical study for the driven Caldeira-Leggett model. Moreover, we determine the decay in Fourier space as a function of the dissipation strength and the temperature.

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Landau-Zener-Stückelberg (LZS) Interferometry in Triple Quantum Dots

Andrew Sachrajda[1]

1. National Research Council of Canada, Canada

Abstract:

In this talk a review will be given of our LZS experiments in triple quantum dots. The triple quantum dot energy level structure is surprisingly complicated in comparison with the more common double quantum dot devices. Multiple anticrossings and rapidly varying exchange terms result in a rich variety of coherent phenomena which can be explored by activating with different pulse characteristics. In particular we find magnetic field dependencies under fixed pulse conditions to be a useful probe to separate distinct behaviours such as the all-exchange qubit or basic LZS effects. Amongst the novel features we have observed is an interference between LZS and exchange effects. The effect can even be observed under conditions where the individual LZS and exchange effects individually cannot. The system also allows us to probe LZS effects originating from two anticrossings in series.

Quantum Bath Engineering in Landau-Zener-Stuckelberg Interferometry

D Dominguez[1], AL Gramajo[1], A Ferron[2], MJ Sanchez[1]

1. Centro Atomico Bariloche and Instituto Balseiro, Argentina.
2. Instituto de Modelado e Innovacion Tecnologica (CONICET -UNNE), Argentina

Abstract:

We study the quantum dynamics of superconducting flux qubits driven by a dc+ac magnetic field and coupled to a quantum bath. We calculate numerically the finite time and the asymptotic statationary population of the qubit states using the Born-Markov-Floquet approach, solving a realistic model of the flux qubit considering up to 10 energy levels. We find that for large ac driving amplitudes, such that there are Landau-Zener-Stuckelberg (LZS) intereferences, the population of the qubit states is strongly influenced both by the structure of the spectral density of the quantum bath, and by the nature of the system-bath coupling. For Ohmic baths we find “bath-mediated” population inversion in the stationary regime. When considering a structured bath with a resonant frequency, we find that the LZS patterns can be strongly affected by the resonanat frequency. Finally, we compare longitudinal with transverse system-bath couplings. (In the case of the flux qubit, "longitudinal" coupling corresponds to flux noise while "transverse" coupling corresponds to charge noise). In the stationary regime, we find that a longitudinal coupling gives a n-photon resonance peak that is asymmetric with respect to the dc magnetic field, while a transverse coupling gives nearly symmetric resonance peaks. When combining both types of coupling, we find that the stationary behavior is dominated by the transverse type of coupling in a wide range of parameters.

Nontrivial High Frequency Limits in Periodically Driven Systems

Anatoli Polkovnikov[1]

1. Boston University, USA

Abstract:

In this talk I will briefly review the Floquet theory describing periodically driven systems. I will focus on high frequency limits, where one can obtain Floquet Hamiltonians perturbatively in the inverse frequency using the Magnus expansion. I will then discuss classes of driving protocols, where one can get non-trivial high frequency limits and illustrate them with examples such as the famous Kapitza pendulum and recently realized artificial magnetic fields in MIT and Munich groups. At the end I will discuss convergence of the Magnus expansion, connection with the many-body localization in the energy space and possible implications for digital quantum computing.

Many-Body Control of Effective Quantum Magnets from Rydberg Atom Lattices

Thomas Pohl[1]

1. Max-Planck-Institute for the Physics of Complex Systems, Germany

Abstract:

By virtue of their large polarizability, ultracold Rydberg atoms provide a promising route for realizing artificial spin systems with strong and long-range interactions.
This talk will present several scenarios for introducing different types of long-range interactions by exploiting the strong van der Waals level-shifts of highly excited Rydberg states, which yield various spin models upon applying specific optical excitation schemes. We will assess different approaches to exploring their ground and low-energy states via coherent laser control or dissipative processes and discuss recent experimental progress towards preparing such phases via slow tuning through avoided crossings in the many-body energy spectrum.

Probing Physics of Dirac Cones by Landau-Zener Interferometry

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2. Université Paris-Sud, F-91405 Orsay, France

Abstract

The so many fascinating properties of graphene, like the massless propagation of the electrons, are the subject of an intense research activity. On the other hand there is a growing interest for the study of "artificial graphenes", that is totally different and new systems which bear exciting similarities with graphene, among them: lattices of ultracold atoms, photonic lattices or "molecular graphene". The advantage of these artificial structures is that they serve as new playgrounds for measuring and testing physical phenomena which may not be reachable in graphene. In particular the possibility of controlling the position of the pair of Dirac points (or Dirac cones) existing in the electronic spectrum of graphene.

These cones, which describe the band structure in the vicinity of the two connected energy bands, are characterized by a topological "charge", that is essentially a Berry phase. The cones can be moved in reciprocal space by appropriate modification of external parameters (pressure, twist, sliding, stress, etc.). They can be manipulated, created or suppressed under the condition that the total topological charge be conserved. The merging between two Dirac cones is thus a topological transition that may be described by two distinct universality classes, according to whether the two cones have opposite or like topological charges [1,2]. At the merging between two Dirac cones of opposite charges, the spectrum is quite surprising: the electrons stay massless along one direction like in graphene, but they become massive in the opposite direction. This hybrid (also called semi-Dirac) regime cannot be reached experimentally in a graphene sheet, since it is impossible to deform it sufficiently without tearing it apart.

Recently, an experimental team in Zürich realized an ultracold gas of atoms moving in a potential landscape designed by laser fields to realize a kind of « artificial graphene » [3]. Atoms now play the role of electrons and laser fields that of the crystalline lattice. This artificial graphene can be manipulated and deformed at will. Using this trick, the experimentalists managed to reach the required limit to observe the merging transition. By accelerating the atoms and measuring their evolution from low to high energy states (i.e. from the valence to follow the scenario of the merging transition.
We have given a complete explanation of these experiments thanks to a model developed in our group [4]. We were able to compute the probability for an atom to get transferred from one band to the other as a function of the direction of acceleration. Thus we could confirm the proposed merging scenario [1,2]. More recently we have studied particularly the situation where atoms are accelerated along the axis of the two Dirac cones and experience two Landau-Zener transitions in a row. In this case, we expect the possibility of quantum interferences in momentum space leading to the yet to be observed Stückelberg oscillations [4]. The interference pattern depends on the trajectory in k-space, on the sign of the topological charges and on the mass sign attached to the Dirac cones [5].

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Landau-Zener Transitions Between Topological and Ordinary Insulators

Mehmet Ozgur Oktel[1]

1. Bilkent University, Turkey

Abstract

Cold atom realization of topological states promise in depth investigation of these novel phases in a highly controllable manner. With such a realization it would be possible to probe topological insulators with non-perturbative time dependent potentials. In this work, we investigate the transition from a topological insulator to an ordinary insulator by time-dependent modification of the Hamiltonian. Such a transition can never be fully adiabatic as topological numbers can only change through closing of the band gap. We find that a sudden switch from a topological to an ordinary insulator always transfers a universal Chern number of 1/6 per Dirac cone to an excited band, even when the number of excited particles is small. Focusing on the Haldane model, we calculate the edge currents and find that the edge current formation is a distinct precursor of the topological transition even in the ordinary insulator state.

From Generalized Landau-Zener Protocols to Transitionless Quantum Driving

Oliver Morsch[1]

1. University of Pisa, Italy

Abstract:

Controlling the dynamics of a quantum system is an important prerequisite for many current and future technologies, ranging from magnetic resonance imaging to quantum computers. Even for the simplest quantum system, the paradigmatic two-level Landau-Zener model, there are infinitely many ways to drive the system from some initial to a desired final state. One can, however, identify two extremal paths in Hilbert space: one that minimizes the time it takes to reach the final state, and another one that maximizes the degree of adiabaticity during the entire driving protocol. Whereas the first ("super-fast") case realizes the quantum speed limit, the second ("super-adiabatic") case corresponds to the transitionless driving protocols recently proposed by Berry and Demirplak and Rice. We show that such transitionless driving protocols can generally be realized by appropriately transforming any two-level driving protocol, and in particular the Landau-Zener protocol. In our experiments using Bose-Einstein condensates in optical lattices we have realized both protocols. In my talk I will discuss our results and demonstrate that, in particular, the super-adiabatic driving protocols are potentially interesting for applications as they are extremely robust to noise and parameter variations.

Quantum Simulations with Quantum Dots Arrays

Pierre Barthelemy[1], Toivo Hensgens[1], Floris Braakman[1], Lieven Vandersypen[1]

1. TU Delft, the Netherlands

Abstract

Quantum Dots Systems have shown to be a very versatile platform where the quantum properties of electrons can be efficiently manipulated. This lead to the development of quantum dot spin qubits, where charge and spin degrees of freedom of single electrons can be efficiently controlled entirely electrically.

In this talk we will discuss our progress towards controlling the electron state on large arrays of quantum dots. This work follows two lines of research: a bottom-up approach where we have full control of each dot individually, and we read out charge and spin states via transport or charge sensing measurements; and a top down approach where, through global control knobs, we define very large arrays of quantum dots simultaneously and access their properties through capacitance spectroscopy.

Manipulating the Nuclear Spins in a Semiconductor Quantum Dot with Frequency-Swept Magnetic Resonance Pulses

Richard J. Warburton[1]

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Abstract

A self-assembled quantum dot represents in some ways a "nano-lab" for investigating ensembles of nuclear spins. At high magnetic fields, the nuclear spins in the quantum dot are largely decoupled from those in the rest of the material. Furthermore, the nuclear spins can be polarized via an optically injected electron spin ("dynamic nuclear polarization"); and the nuclear spin polarization can be read-out via its influence on the optical frequency (the "Overhauser field"). The 100,000 nuclear spins in the work-horse system, an InGaAs quantum dot, are potentially complex: there are 5 main isotopes, all with large nuclear spins and widely different gyromagnetic ratios. In addition, there are strong atom-dependent quadrupole interactions [1]. This problem is of importance as fluctuations in the nuclear spin bath represent the main dephasing mechanism of an electron spin qubit using a quantum dot as host [2]. Fluctuations in the nuclear spins also determine the indistinguishability of single photons emitted by a single quantum dot once charge noise has been suppressed [3,4].

We discuss here nuclear magnetic resonance (NMR) on the nuclear spin ensemble associated with a single InGaAs quantum dot. The main concept is that by sweeping over a large frequency range, the pulse addresses each nuclear spin at some point. For each nuclear spin, the main concept is Landau-Zener physics.

Following polarization of the nuclear spin ensemble (to around 40% of the maximum value), we demonstrate a reversal of the nuclear spin with a single frequency-swept NMR pulse. Using a series of pulses, we can flip the nuclear spin back-and-forth a hundred times before the polarization is lost [4]. For single pulses, as a function of the time required to complete the frequency sweep, we observe initially an exponential increase in NMR, consistent with the Landau-Zener result. However, at intermediate sweep rates we observe a plateau in the NMR signal, followed by a second exponential increase, and a second plateau. These effects go beyond the Landau-Zener description of a two-level system. We demonstrate that the plateau arise from the quadrupole interaction which gives rise to a hierarchy of anticrossings in the energy levels. Remarkably, these effects survive the ensemble averaging. For instance, we achieve inversion at the so-called "first quantum transition" for all isotopes simultaneously. Observation of the plateau allows us to determine many key parameters: the chemical composition of the quantum dot, the initial nuclear spin temperature and the quadrupole frequency distributions for all the main isotopes.

An overriding point is that the Landau-Zener effect represents a generic technique for manipulating nano-scale inhomogeneous nuclear spin ensembles.

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Dissipative Quantum Dynamics at Avoided Crossings

Peter Nalbach[1]

1. Universität Hamburg, Germany

Abstract

We study Landau-Zener transitions in a dissipative environment by means of a numerically exact quasi-adiabatic propagator path integral. We discover a non-monotonic dependence of the transition probability on the sweep velocity. Employing additionally an approximate Markovian master equation allows us to attribute these findings to a nontrivial competition between relaxation and the external driving.

Nanoscale Magnetic Sensing via Multi-Particle Interferometry

Mikhail Lukin[1]

1. Harvard University, USA

Abstract:

Sensitive detection of magnetic signals from nuclear spins is an important problem in science and technology. It forms the basis for nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI), which, over the past few decades, have emerged as essential tools for materials science, biology, and medicine. Because these conventional methods involve detection of a large number of nuclear spins, considerable efforts have been directed toward extending these methods to their ultimate limit, the detection and imaging of single-atom nuclear spins.

We describe and demonstrate a new approach for detecting magnetic resonance signals from individual proton spins using of a network of electronic spin-1/2 qubits on the surface of a high purity diamond under ambient conditions. The state of these ``reporter'' spins is measured via a proximal nitrogen-vacancy (NV) color center via multi-particle analog of Ramsey interferometry.

The detection, imaging and coherent manipulation of the reporter spins enables the observation of coherent dynamics between them and proximal proton spins, as well as the localization of these protons on the surface. Finally, experimental observation of NMR signals from single proteins will be described. Possible applications to NMR and MRI of single molecules are discussed.

Quantum Networks and Quantum Information with Spins in Diamond

Tim Hugo Taminiau

1. TU Delft, the Netherlands

Abstract:

The nitrogen vacancy (NV) center in diamond is a promising candidate to realize quantum networks consisting of multi-qubit nodes optically linked over large distances. In this talk, I will present our recent progress towards this goal. First, I will present how multi-qubit nodes can be formed using the NV electron spin to control and entangle nuclear spins in its environment. As a demonstration I will present the realization of a basic quantum error correction protocol [1]. Second, we will discuss the unconditional quantum teleportation of a nuclear spin to an electron spin in another diamond 3 meters away [2,3]. Together these results provide the basis for establishing quantum networks based on spins in diamond.

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Landau-Zener Quantum Memory and All-Optical Quantum Control in NV Centers

Guido Burkard[1]

1. University of Konstanz, Germany

Abstract:

The electronic spin of nitrogen-vacancy (NV) centers in diamond has remarkable coherence properties and allows for efficient quantum control—preparation, manipulation, and readout—using optical and microwave fields. Moreover, each NV center comprises the even longer-lived nuclear spin of the nitrogen atom. We show how Landau-Zener transitions across a hyperfine-mediated avoided level crossing enable fast storage and retrieval of the electron spin qubit into and from the resident nuclear spin. We further discuss all-optical control of the NV spin using coherent dark states and, finally, a proposal for cavity-mediated two-qubit gates between NV spin qubits.

Recent Progress in Circuit QED

Steven Girvin[1]

1. Yale University, USA

Abstract

A revolution is underway in the construction of 'artificial atoms' out of superconducting electrical circuits[1]. These macroscopic 'atoms' have quantized energy levels and can emit and absorb quanta of light (in this case microwave photons), just like ordinary atoms. This 'circuit QED' has given us the ability to do non-linear quantum optics in electrical circuits at the single photon level. It is now possible to entangle multiple qubits, count individual microwave photons, create record large 'Schrödinger cat' photon states and perform quantum feedback. Theoretical and experimental work is underway towards development of arrays of qubits in microwave cavities to perform quantum simulations of strongly correlated boson models interacting with engineered quantum baths.

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Photon-assisted Tunnelling with Non-classical Light

Aashish Clerk[1]

1. McGill University, Canada

Abstract

Among the most exciting recent advances in the field of superconducting quantum circuits is the ability to coherently couple microwave photons in low-loss cavities to quantum electronic conductors (e.g. semiconductor quantum dots or carbon nanotubes). These hybrid quantum systems are promising for quantum information processing applications; even more strikingly, they enable exploration of completely new physical regimes. In this talk, I'll discuss recent theoretical work exploring new effects which emerge when a quantum electronic conductor is driven by non-classical microwaves (e.g. squeezed states, Fock states). I'll show that the quantum conductor acts as a non-trivial probe of the microwave state; in particular, the emission and absorption of photons by the conductor is characterized by a non-positive definite quasi-probability distribution. This negativity has a direct influence on the conductance of the conductor.

Quantum Thermodynamics in Superconducting Circuits

Jukka P. Pekola[1]

1. Aalto University, Finland

Abstract

I will first present an overview our recent experiments on non-equilibrium fluctuation relations and Maxwell Demon in hybrid superconducting circuits [1-4]. Then I focus on the on-going work towards calorimetric detection of dissipation in quantum circuits, where Landau-Zener physics can be addressed [5,6].

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SU(2) Generalization of the Ambegaokar-Eckern-Schoen Action: Geometric Langevin Noise

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Abstract

The presence of geometric phases is known to affect the dynamics of the systems involved. I will discuss here a quantum degree of freedom moving in a dissipative environment, whose dynamics is described by a Langevin equation with quantum noise. We have recently shown that geometric phases enter the stochastic noise terms. Speciffically, I will consider small ferromagnetic particles (nano-magnets) or quantum dots close to Stoner instability, and investigate the dynamics of the total magnetization in the presence of tunneling coupling to metallic leads. I will present a generalization of the Ambegaokar-Eckern-Schoen (AES) effective action and the corresponding semiclassical equations of motion from the U(1) case of the charge degree of freedom to the SU(2) case of the magnetization. The Langevin forces (torques) in these equations are strongly influenced by the geometric phase. As an example for application, I will discuss low temperature quantum diffusion of the magnetization on the Bloch sphere, which is governed by the geometric phase [1].

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Echo Spectroscopy of Anderson Localization

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Abstract

We propose a conceptually new framework to study the onset of Anderson localization in disordered systems. The idea is to expose waves propagating in a random scattering environment to a sequence of short dephasing pulses. The system responds through coherence peaks forming at specific echo times, each echo representing a particular process of quantum interference. We suggest a concrete realization for cold gases, where quantum interferences are observed in the momentum distribution of matter waves in a laser speckle potential. This defines a challenging, but arguably realistic framework promising to yield unprecedented insight into the mechanisms of Anderson localization.

Direct and Inverse LZS Interferometry and Their Application for Nano-electro-mechanical Systems

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Abstract:

Modern mesoscopic systems allow the realization of regimes which were not attainable before with microscopic systems. Particularly interesting is the strongly-driven regime for solid-state quantum systems. This regime is also referred to as Landau-Zener-Stuckelberg (LZS) interferometry [1], describing the system evolution for a given time-dependent Hamiltonian H(t). Another approach is to reverse-engineer LZS interferometry, where one is interested in finding the system parameters in its Hamiltonian, in order to accomplish a certain task [2]. One example of this is the inverse problem for the Landau-Zener effect; namely, finding the driving Hamiltonian parameters that result in a desired time-dependence for the occupation probabilities [3].

We considered both the direct and the inverse LZS problems for a typical nanoelectromechanical system, which consists of a charge qubit and a nanomechanical resonator [4,5]. In the direct problem, the transitions in the qubit are studied by means of the resonator [4]. Here, the inverse problem is formulated as finding the resonator parameters in the qubit Hamiltonian, from the qubit occupation probabilities.

In this talk I will present the above concept of inverse LZS problem and consider its solutions. In particular, I will discuss the analytical solution within the so-called adiabatic-impulse method [5]. Also the delayed-response approximation will be presented for the description of the resonator quality factor [6]. As a specific example, we apply these results to nano-electro-mechanical systems.

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Time-dependent Control of Light and Sound

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Abstract

Optomechanical systems feature the interaction between nanomechanical vibrations and the light field, brought about by the radiation pressure force. In this talk, I will highlight some aspects of optomechanics where time-dependent control is essential. In the first example, we consider one of the most important realizations of optomechanics, namely a membrane in the middle of an optical cavity. There, vibrations of the membrane can lead to Landau-Zener-Stückelberg oscillations of photons between the two sides of the cavity. In the second example, I will describe how one may exploit the optomechanical interaction to generate synthetic gauge fields for photons. A suitable periodically modulated laser-drive of a photonic crystal brings about mechanical vibrations that in turn give a phase to photons hopping between localized optical modes. As a result, chiral edge states of photons can form along the sample boundary, and these are resistant to disorder.

Coherent Control of Strongly Coupled Nanomechanical Modes

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Abstract

Nanomechanical resonators are freely suspended, vibrating bridges with nanoscale diameters. These nanostructures are receiving an increasing amount of attention, both in fundamental experiments addressing the foundations of quantum mechanics and for sensing applications, and show great promise as linking elements in future hybrid nanosystems.

In particular, doubly-clamped pre-stressed silicon nitride string resonators are explored as high Q nanomechanical systems enabling room temperature quality factors of several 100,000 in the 10 MHz eigenfrequency range. Electrically induced gradient fields are employed to implement dielectric transduction as an efficient way to actuate and probe these nanostrings and to tune their eigenfrequencies over a wide frequency range [1,2]. The two orthogonal fundamental flexural modes of the string vibrating in- and out-of-plane with respect to the sample surface can be engineered to tune in opposite direction. Thus, both modes can be brought into resonance where a pronounced avoided crossing is observed, indicating that the mechanical modes are strongly coupled.

A pulsed measurement scheme is used to analyze the time-dependent evolution of a previously initialized mode as it is tuned across the coupling region. At slow sweep rates, the system adiabatically follows the energy eigenstates, whereas the energy is transferred from one branch to the other during fast sweeps. The measured classical transition probabilities show excellent agreement with Landau-Zener theory [3]. Furthermore, the demonstrated time-domain control allows deep insights into the nanomechanical classical two-mode system defined by the lower and upper hybrid mode of the avoided crossing. To this end electromagnetic pulse techniques well known from coherent control of two-level systems in atoms, spin ensembles, or quantum bits and the corresponding Bloch sphere picture are introduced to nanomechanical systems [4]. Full Bloch sphere control is demonstrated by Rabi, Ramsey and Hahn echo experiments. Moreover, we find that all relaxation times T1, T2 and T2* are equal. This not only indicates that energy relaxation is the dominating source of decoherence, but also demonstrates that reversible dephasing processes are negligible in such collective mechanical modes. We thus conclude that not only T1 but also T2 can be increased by engineering larger mechanical quality factors. After a series of ground-breaking experiments on ground state cooling and non-classical signatures of nanomechanical resonators in recent years, this may be of particular interest for quantum nanomechanical systems in the context of quantum information processing.

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Landau - Zener Interferometry in Multilevel Systems

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1. ICTP, İtaly

Abstract

We propose a universal approach to the Landau-Zener (LZ) problem in a multilevel system. The problem is formulated in terms of generators of SU(N) algebra and maps the Hamiltonian onto the effective anisotropic pseudospin (N-1)/2 model. The vector Bloch equation for the density matrix describing the temporal evolution of the multilevel crossing problem is derived and solved analytically for two generic cases: i) three-level crossing problem representing a minimal model for a LZ interferometer and ii) four-level crossing problem corresponding to a minimal model of coupled interferometers. It is shown that the analytic solution of the Bloch equation is in excellent quantitative agreement with the numerical solution of the Schroedinger equation for the 3- and 4- level crossing problems. The solution demonstrates oscillation patterns which radically differ from the standard patterns for the two-level Landau- Zener problem: “beats” when the dwell time in the interferometer is smaller compared to a tunnel time and “steps” in the opposite limit. The possibilities of the experimental realization of LZ interferometers in the system of coupled quantum dots, Josephson charge qubits and in two-well traps for cold gases are discussed.

Stückelberg Interferometry in a Hexagonal Lattice

Ulrich Schneider[1]

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Abstract

There has been recent renewed interest in the geometric structure of individual energy bands in solids, which forms the basis for intriguing many-body states such as Quantum Hall- and topological insulators. This geometric structure is encoded in the Berry phases that particles acquire when performing closed adiabatic loops in the Brillouin zone. Beyond single bands, these Berry phases generalize to matrix-valued Wilson loops, which give rise to even richer physics, including the potential for holonomic quantum computing. We have performed Stückelberg interferometry with ultracold atoms in a Graphene-type hexagonal optical lattice. Here, the band geometry is governed by two Dirac cones connecting the lowest two bands. We have measured both the dispersion relation as well as the off-diagonal Berry connection between the bands. This connection not only reveals the topological structure of the Dirac points but also gives rise to the intriguing phenomenon that, even in the limit of fast accelerations, one full Bloch oscillation does not correspond to the identity operator; rather, three Bloch oscillations are required to return the particle to its initial state. In combination with our recent independent Berry phase measurements, Stückelberg interferometry provide a framework for the full determination of the geometric tensor of Bloch bands in periodic structures.

Stripe-ordered Superfluid, Supersolid and Vortex Lattice phases in Attractive Hofstadter-Hubbard Model

Menderes Iskin[1]

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Abstract

In this talk, I will explore the ground-state phase diagram of the single-band attractive Hofstadter-Hubbard model on a square lattice. I will show that the interplay between the Hofstadter butterfly and superfluidity breaks spatial symmetry, and gives rise to stripe-ordered superfluid, supersolid and vortex lattice phases in large parameter spaces. I will also discuss the effects of a trapping potential and comment on the viability of observing stripe-ordered phases with cold Fermi gases. See, M. Iskin, arXiv:1406.6890 (2014), for more details.

Band Crossing Dynamics with Superfluid Bosons

Andreas Hemmerich[1]

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Abstract

I will discuss recent experiments with ultracold bosonic quantum gases where Landau Zener and relaxation dynamics is observed close to topological crossings between higher bands of an optical lattice.

POSTER PRESENTATIONS

Probing Hyperfine-induced Nuclear Spin Dynamics in Quantum Dots

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The hyperfine interaction is central to spin qubits in solid state systems, especially in GaAs/AlGaAs-based quantum dots. It causes electron spin dephasing, but also gives access to the nuclear spin ensemble. Previously, we demonstrated in transport experiments how the inhomogeneous field of an on-chip single-domain nanomagnet can help to dynamically polarize nuclear spins beyond 50% [1]. Here, we explore a double quantum dot including two on-chip nanomagnets. Compared to a single magnet it incorporates a stronger inhomogeneous magnetic field which is rotated between the two dots. We find that this gives rise to a more complex nuclear spin dynamics characterized by several alternative fixed points. Besides dc transport measurements we also probe the nuclear spin polarization by means of electron dipole-induced spin resonance (EDSR). The fixed points can be classified by means of the dc current flowing through the double quantum dot and by their varying polarization dynamics. The decay time constant of the nuclear spin polarization monitored by EDSR can be significantly increased from 1 up to to more than 15 minutes by increasing the time of dynamic nuclear spin polarization.

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Qubit interference at avoided level crossings: The role of driving shape and bath coupling

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Abstract

We derive the structure of the emerging Landau-Zener-Stückelberg-Majorana (LZSM) interference pattern for a qubit with time-periodic but otherwise general driving. In Fourier space, this pattern exhibits an arc structure with a shape that depends on the specific driving field. We show that only for time-reversal symmetric driving, it is given by the dynamical phase of the qubit, while generally such a relation does not hold. We support our analytical findings by a numerical study of the ac driven spin-boson model which reveals that the whole structure can be obtained from the non-equilibrium population of the Rabi model beyond rotating-wave approximation. Moreover, we determine the decay of the arcs as a function of dissipation strength and temperature.

Sisyphus Cycles for a Nano-Electro-Mechanical System

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Abstract

Landau-Zener-Stuckelberg interferometry is a powerful tool for studying microscopic and mesoscopic systems [1]. In particular, such a regime can be studied via nano-electro-mechanical systems (NEMS), such as in Ref. [2]. Recently, we developed a semiclassical theory for the delayed response of a quantum dot to oscillations of a nanomechanical resonator. We demonstrated that the back-action of the quantum dot changes both the resonant frequency and the quality factor of the resonator [3]. An increase or decrease in the quality factor of the resonator corresponds to either the enhancement or damping of the oscillations, which can also be interpreted as Sisyphus amplification or cooling of the nanomechanical resonator by the quantum dot, similar to Refs. [4,5].

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Atom-photon Entanglement in Four-level Double-lambda Configuration

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Abstract

The entanglement between the dressed atom and its spontaneous emission in four-level double lambda is studied in semi classical approach. The quantum entropy of these two subsystems is investigated by using the von Neumann entropy in the closed loop and non-closed loop configuration. It is shown that in both of these configurations the steady state maximum entanglement can occur in multi photon resonance condition and in the special parameters of Rabi frequenciesof optical laser fields. In the absence of quantum interference in this system the relative phase is not a good parameter for controlling the behavior of entanglement.In fact the behavior of entanglement is much more sensitive towards the Rabi frequencies rather than relative phase. It is illustrated by increasing the strength of driving fields on these system entanglement is increased and the multi wave mixing of non-linearity effects generates the entanglement.

Observation of Landau-Zener-Stückelberg Oscillations of a Singlet-triplet Qubit Using Metastable Charge States for Spin to Charge Conversion

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3. Department of Electrical and Computer Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada

Qubits formed using the singlet and triplet two-spin states in semiconductor double quantum dots have received much attention recently [1-4]. Qubit state read-out using a charge detector and thus the observation of coherent Landau-Zener-Stückelberg oscillations relies on the process of spin to charge conversion. These oscillations are normally observed in the (2,0) region of the stability diagram because this process usually involves projecting a (1,1) singlet onto the (2,0) ground state. We have found that oscillations of the spin qubit can also be detected in the (1,0) read-out regime. In the regime of our experiment, the (1,1) triplet state of the qubit is converted to the (1,0) ground state while the (1,1) singlet state has high transition probability to the (2,0) state. Within the (1,0) regime, (2,0) is the first excited state. The excited state starts playing an important role in the spin to charge conversion process because it is metastable as the left dot is almost pinched off from its lead and instead is charged via a slow cotunneling process from the right lead.

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Interplay of Spin-orbit and Hyperfine Interactions in Dynamical Nuclear Polarization in Semiconductor Double Quantum Dots

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Abstract

We explore the interplay of spin-orbit and hyperfine effects on the nuclear preparation schemes in two-electron double quantum dots in $In_xGa_{1-x}As$. The quantity of utmost interest is the electron spin decoherence time T_2^* in dependence of the number of sweeps through the electron spin singlet S triplet T_+ anti-crossing. Decoherence of the electron spin is caused by the difference field induced by the nuclear spins [1]. We study the case where a singlet $S(2, 0)$ is initialized, in which both electrons are in the left dot. Subse- quently, the system is driven repeatedly through the anti-crossing and back using linear electrical bias sweeps. Our model describes the passage through the anti-crossing with a large number of equally spaced, step-like parameter increments. We develop a numeri- cal method describing the nuclear spins fully quantum mechanically, which allows us to track their dynamics. Both Rashba and Dresselhaus spin-orbit terms do depend on the angle θ between the [110] crystallographic and the inter-dot axis [2]. Our results show that the suppression of decoherence (and therefore the enhancement of T_2^*) is inversely proportional to the strength of the spin-orbit interaction, which is tuned by varying the angle θ Fig. 1.

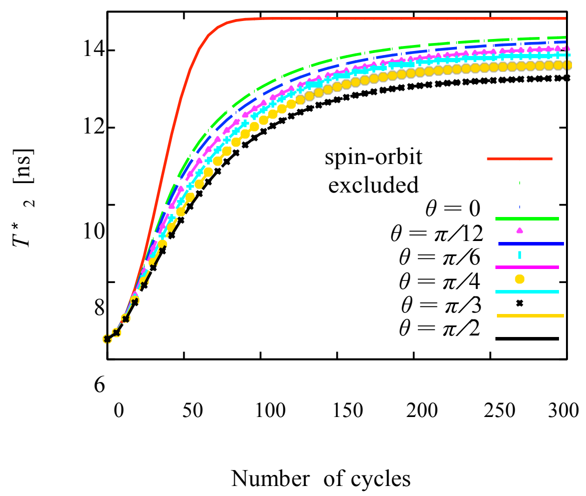

Figure 1: $S - T^+$ decoherence time in $In_{0.2}Ga_{0.8}As$ as a function of the number of cycles for different crystallographic angles θ and for $N = 150$ spins per dot.

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Landau-Zener-Stückelberg Interferometry Transition in a Quantum Wire

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Abstract

Landau-Zener-Stückelberg (LZS) interferometry has been extensively investigated in the open-multibands quantum two-level systems; with particular interests on the subbands n=0, n=1, n=2 and n=3 in a heterostructure 3D quantum wire. Increasing the driving field amplitude and the confinement frequency, more degenerated energy levels are observed, which results in population inversion and many interesting interference patterns. Furthermore, fast driving amplitude of field and strong confinement spin permits a fast and reliable control of the quantum system. It is shown that both the confinement frequency and the driving amplitude field influence, not only the accumulated relative phases, (commonly known as the St**ü**ckelberg phase) but the probability amplitudes as well.

Also, it is demonstrated that the transition probabilities in ballistic subbands can be interpreted in terms of interference and the driving frequency and amplitude of this interference are modulated by interplay of the confinement frequency and the driving amplitude field. In this article, we give a universal description of the characteristics observed in low-frequency regimes. Without explaining the already observed experimental results, our numerical observation shows many interesting phenomena, which can be demonstrated by future experiments.

Landau−Zener−Stückelberg Interference and Lasing in Circuit QED

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Abstract

A linear sweep of a quantum two-level system through its avoided energy level crossing leads to non-adiabatic transition at the avoided crossing. This transition, from ground to excited state across energy gap Δ, is known as the Landau-Zener tunneling. Periodical sweeping of the qubit state through the avoided level crossing induces subsequent Landau−Zener transitions leading to Landau-Zener-Stückelberg interference [1].

We report experimental evidence of Landau-Zener-Stückelberg interference in a superconducting flux qubit [2] strongly coupled to coplanar waveguide resonator [3][4]. The transmission properties of the qubit-resonator system were investigated by weak probing signal at the resonator's fundamental frequency f_0~2.5 GHz. Its dependence on the magnetic flux Φ and on the amplitude of a strong driving signal at $f_d = 3f0$ was measured by microwave network analyzer. The transmission of the resonator was strongly enhanced or suppressed as a periodic function of the amplitude of the applied driving signal and the magnetic flux Φ, revealing Landau-Zener-Stückelberg interference pattern [5] up to 8 photon resonances and 4 interference fringes. The significant enhancement of the resonator's transmission (~10 dB) along with strong bandwidth narrowing indicate lasing effect in the system [6][7] and can be utilized for signal amplification.

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Dynamics Driven Dissipation in Stückelberg Interferometry

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Landau-Zener-Stückelberg-Majorana (LZSM) physics has been exploited to coherently manipulate two-electron spin states in a GaAs double quantum dot (DQD) system at an anti-crossing between a singlet S and a triplet T_+ resulting from the hyperfine interaction with nuclear spins of the host material [1,2]. However, the fluctuations of the nuclear spin bath result in spin dephasing within T^*_2 ~10-20 ns. As a consequence, the sweep through the anti-crossing would have to be performed on a timescale comparable to T^*_2 to achieve LZSM oscillations with 100% visibility. Moreover, the S-T_+ anti-crossing is located near the (1,1) - (2,0) interdot charge transition, where ($\mathbf{n}_l$, $\mathbf{n}_r$) denotes the number of electrons in the left and right quantum dot. As a result the singlet state involved in the dynamics is a superpostion of (1,1) and (2,0) singlet states. Since spin and charge degrees of freedom are correlated, the qubit is also susceptible to charge noise. Although it has been demonstrated how to use tailored pulses to minimize both the effects of charge and nuclear spin noise [3,4], a complete understanding of the effects of charge noise on the dynamics is still lacking.

Here, we present a method to derive approximate analytical _nite-time solutions for the LZSM problem in the presence of noise. Our formalism naturally shows how the LZSM sweep modi_es the dissipation. Moreover, it provides a simple framework to derive generalized propagators that can be used to study Stückelberg interferometry in the presence of dissipation.

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SU(3) semi-classical representation of quantum dynamics of interacting spins

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We present a formalism for simulating quantum dynamics of lattice spin-one systems by first introducing local hidden variables and then doing semiclassical (truncated Wigner) approximation in the extended phase space. In this way we exactly take into account the local on-site Hamiltonian and approximately treat spin-spin interactions. In particular, we represent each spin with eight classical SU(3) variables. Three of them represent usual spin components and five others are hidden variables representing local spin-spin correlations. We argue that this method becomes asymptotically exact in high dimensions. This method allows for access to both non-equal time and spatial correlations. We compare our formalism with exact quantum dynamics of fully connected spin systems and find very good agreement. As an application we discuss quench dynamics of a Bose-Hubbard model near the superfluid-insulator transition for a 3D lattice system consisting of 1000 sites.

Transport Properties of GaAs/AlGaAs/GaAs Core/Shell/Cap Nanowires

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3. Nanosystem Initiative Munich, Schellingstrasse 4, 80799 München, Germany.

Abstract

In this poster, the electrical properties of a novel core/shell/cap nanowire structure of GaAs/AlGaAs/GaAs with 30% Aluminum and Si delta doping is demonstrated. Delta doping in AlGaAs shell layer supplies charge carriers to GaAs core. Remote doping the high electron mobility GaAs core makes it a promising candidate for high speed electronics and quantum control. However, the 2D electron system at the interface of the GaAs core and AlGaAs shell is not easily accessible. Here we demonstrate the preparation of Ohmic contact to 2D electron gas using AuGe/Ni/Ti/Au layer system. To explore the application of these wires in quantum information technology, single and multiple quantum dots structures have been defined using back-gate and local electrostatic bottom gates. Our latest low temperature transport measurements on these quantum dots are reported and discussed.

Control of Ion Channel Transport via Landau-Zener Dynamics

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Abstract

We study transport in biological Ion channels by a simplyfied Two Level System model, using the combination of Quapi and a Lindblad master equation for the system propagation to model ion transport. We find optimal transport if the tunneling strength is roughly equal to the transport strength

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