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Haohua Wang, Zhejiang University

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GENERAL INFORMATION

Venue

5 July:
Rm. S101 & S106, Teaching Building,
UCAS, Zhong-Guan-Cun Campus;
6-7 July:
Rm. 236, Building M, IOP, CAS,
No.3 Zhong-Guan-Cun Nan-Yi-Tiao
Road, Haidian District, Beijing, China.

A map of KITS and its neighbourhood including the location of hotels can be found at the back of this handbook.

Website

http://qcs2017.csp.escience.cn/

Presentation Preparation

PowerPoint slides should be uploaded before presentations during breaks, preferably one day prior to the start of their session to ensure that slides are loaded successfully.

Internet-Wireless

All delegates have access to the UCAS free wireless Internet service. The user name and password will be announced during the forum.

Registration

The registration desk will be at the lobby of Jun Ma International Hotel during
14:00-18:00, 4 July
Or Room S106 at UCAS,
Zhong-Guan-Cun Campus during the following hours:
14:00-18:00, 4 July
08:30-17:00, 5-7 July

Catering

Morning and Afternoon Tea Breaks
Tea breaks during the forum will be served outside the meeting rooms

Welcome Banquet

18:30, 6 July (invitation card required)
Buses will departure at 18:00 outside the meeting room building to Quanjude Peking Duck Restaurant

Nearby Cafes and Restaurants

There are numerous cafes and restaurants near KITS. Have fun with Chinese food and language!

KITS Conference on Quantum Computation and Simulation

5 - 7 July, 2017, Beijing, China

PROGRAM

4 July

14:00-18:00 Registration *Jun Ma International Hotel & Room S106, KITS*

5 July

Chair: **Li Lu**, IOP, CAS *Room S106, KITS*

08:30-08:50 On-site Registration

08:50-09:00 **Fuchun Zhang**, KITS
Opening & Introduction of KITS

Session 1: Superconducting qubits

Chair: **Tao Xiang**, IOP, CAS *Room S106, KITS*

09:00-09:40 **Robert McDermott**, Univ. Wisconsin-Madison
Measurement and control of superconducting qubits using single flux quantum digital logic

09:40-10:20 **Yu Chen**, Google/UCSB
Building quantum annealer V2.0

10:20-10:50 Coffee Break

Session 2: Superconducting qubits

Chair: **Yang Yu,** Nanjing Univ. *Room S106, KITS*

10:50-11:30 **Simon Gustavsson**, MIT
Dynamical control techniques with superconducting qubits

11:30-12:10 **Yuxi Liu**, Tsinghua Univ.
Electromagnetically induced transparency in superconducting quantum circuits: From classical to quantum

12:10-14:00 Lunch

Session 3: Public lecture on artificial intelligence

Chair: **Fuchun Zhang**, KITS *Room S101, KITS*

14:00-15:30 **Hartmut Neven**, Google
An Update from the Google Quantum Artificial Intelligence Lab

15:30-16:00 Coffee Break

Session 4: Quantum simulation and computation

Chair: **Dapeng Yu**, Southern U of S&T ***Room S101, KITS***

16:00-16:40 **Shuai Chen**, USTC
Quantum simulation of spin-orbit coupling with Bose gas

16:40-17:10 **Haohua Wang**, Zhejiang Univ.
A 10-qubit superconducting quantum processor for emulating anyonic fractional statistical behavior

17:10-17:50 **Xiaobo Zhu**, USTC
On resonance quantum switch by longitudinal control field and demonstration of solving linear Equations by superconducting quantum circuits

17:50-19:30 Dinner

6 July

Session 5: Superconducting qubits

Chair: **Haohua Wang**, Zhejiang Univ. ***Room 236, Building M, IOP***

09:00-09:40 **Jaw-Shen Tsai**, RIKEN/Tokyo Univ. Science
Superconducting circuit QED for quantum annealing, computing, and simulation

09:40-10:20 **Tiefu Li,** CSRC
Nonlinearity in superconducting circuits

10:20-10:50 Coffee Break

Session 6: Superconducting qubits

Chair: **Jaw-Shen Tsai**, RIKEN/Tokyo Univ. Science ***Room 236, Building M, IOP***

10:50-11:30 **Hanhee Paik**, IBM
IBM Quantum Experience

11:30-12:10 **Shi-Liang Zhu**, Nanjing Univ.
The shortcut-to-adiabaticity and its application to quantum computation

12:10-14:00 Lunch

Session 7: Superconducting qubits

Chair: **Yuxi Liu**, Tsinghua Univ. ***Room 236, Building M, IOP***

14:00-14:40 **Lin Tian**, UC Merced
Quantum simulation and dynamical quantum phase transition with superconducting circuits

14:40-15:20 **Michael Marthaler**, KIT
Quantum chemistry using superconducting qubits
15:20-15:50 (flexible)

15:50-16:20 Coffee Break

Session 8: More qubits

Chair: **Lin Tian**, UC Merced ***Room 236, Building M, IOP***
16:20-17:00 **Guoping Guo**, USTC
Higher symmetry Kondo effect in quantum dots
17:00-17:30 **Heng Fan**, IOP, CAS
Long-time entanglement logarithm growth for many-body localization in a superconducting quantum processor
17:30-17:50 Open Mic Discussion

17:50-20:00 Banquet

7 July

Session 9: Topological quantum computation

Chair: **Hongqi Xu**, Peking Univ. ***Room 236, Building M, IOP***
09:00-09:40 **Felix von Oppen**, Freie Univ.
Color code quantum computation with Majorana bound states
09:40-10:20 **Yaoyi Li**, SJTU
Majorana zero mode in the vortex of an artificial topological superconductor

10:20-10:50 Coffee Break

Session 10: Topological quantum computation

Chair: **Felix von Oppen**, Freie Univ. ***Room 236, Building M, IOP***
10:50-11:30 **Hongqi Xu**, Peking Univ.
Topological superconducting devices made from semiconductor nanostructures
11:30-12:10 **Hao Zhang**, TU Delft
Majorana zero modes in semiconductor nanowires

12:10-14:00 Lunch

Session 11: Topological quantum computation

Chair: **Martin Plenio**, Ulm Univ. ***Room 236, Building M, IOP***

14:00-14:40 **Ke He**, Tsinghua Univ.
Quantum anomalous Hall system as a platform to study topological quantum computation
14:40-15:20 **Peter Stano**, RIKEN
Resistance of the edge mode of a 2D topological insulator
15:20-15:50 **Li Lu**, IOP, CAS
Search for Majorana zero modes in rf-SQUIDs constructed on Bi_2Se_3 surface

15:50-16:20 Coffee Break

Session 12: Quantum simulation and computation

Chair: **Heng Fan**, IOP, CAS ***Room 236, Building M, IOP***

16:20-17:00 **Martin Plenio**, Ulm Univ.
Diamond quantum devices: From quantum simulation to hyperpolarised magnetic resonance imaging
17:00-17:40 **Kihwan Kim**, Tsinghua Univ.
Trapped ion system for molecular spectroscopy
17:40-18:00 Open Mic Discussion & Closing

18:00-19:30 Dinner

ABSTRACT CONTENTS

Measurement and Control of Superconducting Qubits Using Single Flux Quantum Digital Logic

Robert McDermott

University of Wisconsin, Madison

One of the remarkable recent discoveries in information science is that quantum mechanics can lead to efficient solutions for problems that are intractable on conventional classical computers. While there has been tremendous recent progress in the realization of small-scale quantum circuits comprising of order 10 quantum bits (“qubits”), research indicates that a fault-tolerant quantum computer that exceeds what is possible on existing classical machines will require a network of thousands or millions of qubits, far beyond current capabilities. Robust approaches to the measurement and control of large-scale next-generation quantum machines have yet to be developed.

In this talk I describe an experimental program to develop high-fidelity qubit measurement and control circuitry based on the superconducting Single Flux Quantum (SFQ) digital logic family. Qubit measurement is performed by mapping the state to the microwave photon occupation of a linear resonator followed by subsequent microwave photodetection. This scheme provides access to the binary digital output of qubit measurement at the millikelvin experimental stage, without the need for room-temperature heterodyne measurement and thresholding. Coherent control of the qubit is performed using complex trains of quantized SFQ voltage pulses derived from optimal control theory. Each of these pulses provides a delta function-like kick to the qubit, inducing a complex trajectory on the Bloch sphere that is tailored to minimize leakage errors. These two efforts point a direction toward the integration of a large-scale superconducting quantum processor with proximal classical superconducting logic for the purposes of reducing latency, wiring heat load, and overall system footprint.

Building quantum annealer V2.0

Yu Chen

Google/UCSB

Quantum annealer, constructed from an array of coupled flux qubits, holds promises for improving solutions to hard optimization problems with quantum enhancement. In Quantum A.I. Lab, we are working on building an enhanced-performance quantum annealer - quantum annealer v2.0. Using coplanar waveguide-based ‘fluxmon’ qubits, we construct quantum annealer V2.0 as a multi-layer circuit, integrated with flip chip technology and airbridge crossovers. Under such a structure, we demonstrated GHz level qubit-qubit coupling at a minimal control crosstalk, an essential requirement for quantum annealers. Meanwhile, without utilizing lossy amorphous dielectrics, we were able to retain the qubit coherence while dramatically increasing the complexity of the circuit. We will conclude by discussing why such an architecture is suitable for small-scale quantum annealers with enhanced connectivity and coherence.

Dynamical control techniques with superconducting qubits

Simon Gustavsson[1], Fei Yan[1], Gianluigi Catelani[2], Jonas Bylander[3], Jeffrey Birenbaum[4], David Hover[4], Danna Rosenberg[4], Gabriel Samach[4], Steven J. Weber[4], Jonilyn L. Yoder[4], John Clarke[5], Andrew J. Kerman[4], Fumiki Yoshihara[6], Yasunobu Nakamura[6,7], Terry P. Orlando[1], William D. Oliver[1,4]

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[4] *MIT Lincoln Laboratory, 244 Wood Street, Lexington, MA, USA*
[5] *Department of Physics, University of California, Berkeley, CA, USA*
[6] *The Institute of Physical and Chemical Research (RIKEN), Wako, Japan*
[7] *Research Center for Advanced Science and Technology, University of Tokyo, Japan*

Dynamical error suppression techniques are commonly used to improve coherence in quantum systems. They reduce dephasing errors by applying control pulses designed to reverse erroneous coherent evolution driven by environmental noise. However, such methods cannot correct for irreversible processes such as energy relaxation (T1). In this work, we investigate a complementary, stochastic approach to reducing errors: instead of deterministically reversing the unwanted qubit evolution, we use control pulses to shape the noise environment dynamically. In the context of superconducting qubits, we implement a pumping sequence to reduce the number of unpaired electrons - quasiparticles - in close proximity to the device. We report a 70% reduction in the quasiparticle density, resulting in a threefold enhancement in qubit relaxation times, and a comparable reduction in coherence variability [1].

In a separate experiment, we investigate qubit dephasing (T2) due to photon shot noise in a flux qubit transversally coupled to a coplanar microwave resonator. Due to the AC Stark effect, photon fluctuations in the resonator cause frequency shifts of the qubit, which in turn lead to dephasing. While this is universally understood, we have made the first quantitative spectroscopy of this noise for both thermal (i.e., residual photons from higher temperature stages) and coherent photons (residual photons from the readout and control pulses). By mapping out the noise power spectral density seen by the qubit, we uniquely identify thermal shot noise as the dominant source of dephasing. When implementing the CPMG dynamical-decoupling protocol, we are able mitigate to the adverse influence of the photon shot noise, and improve T2 Echo ~ 40 us to reach T2 CPMG ~ 80 us ~ 2*T1. Furthermore, by improving the filtering for thermal noise in a subsequent cooldown, we are able to reduce the residual photon population to 0.0004, resulting in T2 echo times approaching 100 us [2].

[1] Science 354, 1573 (2016)

[2] Nature Communications 7, 12964 (2016)

Electromagnetically induced transparency in superconducting quantum circuits: From classical to quantum

Yu-xi Liu

Institute of Microelectronics, Tsinghua University, Beijing 100084, China
Tsinghua National Laboratory for Information Science and Technology, Beijing 100084, China

In this report, I will mainly discuss how to realize electromagnetically induced transparency (EIT) and Aulter-Townes splitting (ATS) in superconducting quantum circuits. I will introduce several new research results when the classical control field is changed to the quantum control field. In particular, I will show how to discern EIT and ATS spectra when the mean photon number of the quantum control field is changed from zero to the finite number.

[1] Electromagnetically induced transparency and Autler-Townes splitting in superconducting flux quantum circuits, Hui-Chen Sun, Yu-xi Liu, Hou Ian, J. Q. You, E. Il'ichev, and Franco Nori, Phys. Rev. A 89, 063822 (2014)

[2] Polariton states in circuit QED for electromagnetically induced transparency, Xiu Gu, Sai-Nan Huai, Franco Nori, and Yu-xi Liu, Phys. Rev. A 93, 063827 (2016)

[3] Vacuum induced transparency and photon number resolved Autler-Townes splitting in a three-level system, J. H. Ding, S. N. Huai, Hou Ian, Yu-xi Liu (submitted to Phys. Rev. A)

[4] Vacuum induced Aulter-Townes splitting in a superconducting artificial atom, Z.H. Peng, J.H. Ding, Y. Zhou, L.L. Ying, Z. Wang, L. Zhou, L.M. Kuang, Yu-xi Liu, O. Astfiev, J.S. Tsai, arXiv:1705.11118

[5] Electromagnetically induced transparency in circuit QED with nested polariton states, Junling Long, H. S. Ku, Xian Wu, Xiu Gu, Russell E. Lake, Mustafa Bal, Yu-xi Liu, David P. Pappas, arXiv:1704.08777

An Update from the Google Quantum Artificial Intelligence Lab

Hartmut Neven

Google Quantum Artificial Intelligence Lab

In this talk I will report about ongoing efforts at the Google Quantum AI Lab to engineer a processor that is capable of passing the quantum supremacy frontier. This is defined as the moment when a quantum processor becomes capable of executing a computational task in a short time, say one second, while even the fastest classical supercomputer cannot perform this task within a reasonable time frame, say one year. Once the supremacy milestone is achieved we plan to offer access to our quantum processors via Google Cloud for researchers and practitioners to be able to explore their potential computational powers. I will discuss which useful application we hope to run on such near-term quantum processors which have passed the quantum supremacy frontier but do not yet possess enough qubits to perform quantum error correction. I will discuss three application areas: quantum simulation, quantum enhanced optimization and quantum neural networks. In particular I will report on i) a recent breakthrough in quantum simulation that suggests that one only needs a circuit of depth O(n) to perform electronic structure calculations involving n spin orbitals ii) quantum parallel tempering, a newly designed quantum enhanced optimization technique, that uses the physics of many body delocalization to escape local minima and finally iii) first experiments to train quantum neural networks.

Quantum Simulation of Spin-Orbit Coupling with Bose Gas

Shuai Chen

University of Science and Technology of China

We report the experiment of quantum simulations with synthetic spin-orbit coupled Bose gas. First, Spin-Orbit (SO) coupling in 1D with ultracold Bose gas of ^{87}Rb was generated with Raman coupling technique. The fundamental properties of SO coupled Bose gas were systematically studied, including the dipole oscillation of the collective modes, the zero and finite temperature phase diagram of the ground states, and the observation of excitation spectrum with contains “phonon-maxon-roton” structure. Very recently, we have proposed and experimentally realized, for the first time, 2D SO coupling and topological bands with ^{87}Rb BEC through a 2D optical lattices together with a phase correlated Raman coupling lattice. A controllable crossover between 2D and 1D SO couplings is studied, the SO effects and nontrivial band topology are also observed by measuring the atomic cloud distribution and spin texture in the first Brillouin zone. Our achievements open a new way in the field of quantum simulation to study the topological quantum matter.

[1] J. –Y. Zhang, S. –C. Ji, Z. Chen, L. Zhang, Z. –D. Du, B. Yan, G. –S. Pan, B. Zhao, Y. –J. Deng, H. Zhai, S. Chen, and J. –W. Pan, Phys. Rev. Lett. 109, 115301 (2012).

[2] S. –C. Ji, J. –Y. Zhang, L. Zhang, Z. –D. Du, W. Zheng, Y. –J. Deng, H. Zhai, S. Chen, and J. –W. Pan, " Experimental Determination of Finite Temperature Phase Diagram of Spin-Orbit Coupled Bose Gas" Nature Physics 10, 315 (2014) doi: 10.1038/nphys2905.

[3] S. –C. Ji, L. Zhang, X. –T. Xu, Z. Wu, Y. –J. Deng, S. Chen and J. –W. Pan, Phys. Rev. Lett. 114, 103601 (2015).

[4] Zhan Wu, Long Zhang, Wei Sun, Xiao-Tian Xu, Bao-Zong Wang, Si-Cong Ji, Youjin Deng, Shuai Chen, Xiong-Jun Liu, and Jian-Wei Pan, Realization of 2-dimensional Spin-Orbit coupling for Bose-Einstein Condensate, Preprint at http://arXiv.org/abs/1511.08170 (2015).

A 10-qubit superconducting quantum processor for emulating anyonic fractional statistical behavior

Haohua Wang

Zhejiang University

Here I will review our recent activities with our collaborators on designing and fabricating various superconducting circuits for scalable quantum information processing. In particular, I will introduce a superconducting quantum processor featuring 10 individually-accessible Xmon qubits that are controllably coupled to a bus resonator, based on which we deterministically produce the Greenberger-Horne-Zeilinger states with up to 10 qubits, the largest entanglement created so far in solid state architectures. The effective qubit-qubit interactions, mediated by the bus resonator, can be tailored to entangle arbitrarily chosen qubits. This feature allows us to dynamically generate the ground and excited states of the toric code model, i.e., 7-qubit graph states, based on which we implement the anyonic braiding operation with single-qubit rotations for emulating anyonic fractional statistical behavior.

On Resonance Quantum Switch by Longitudinal Control Field and Demonstration of Solving Linear Equations by Superconducting Quantum Circuits

Xiaobo Zhu

University of Science and Technology of China

In this talk, I will first show an experimental demonstration of a quantum switch by longitudinal control. In artificial systems, e.g., superconducting quantum devices, all directional couplings including longitudinal coupling can be engineered in principle. Our experiment show that the longitudinal control field can be used to dynamically switch on or fully off the resonant coupling between the qubit/qubit or qubit/resonantor, while the coherent time keeps at 15μs. This approach suggests a new way to control coupling among qubits and data buses by longitudinal control fields, and can be scaled up to large scale quantum chips without any auxiliary circuit.

I will also show that we have used a four-qubit superconducting quantum processor to solve a two-dimensional system of linear equations based on a quantum algorithm proposed by Harrow, Hassidim, and Lloyd [Phys. Rev. Lett. 103, 150502(2009)], which promises an exponential speedup over classical algorithms under certain circumstances. We benchmark the solver with quantum inputs and outputs, and characterize it by non-trace-preserving quantum process tomography, which yields a process fidelity of 0.837 ± 0.006. This results highlight the potential of superconducting quantum circuits for applications in solving large-scale linear systems, a ubiquitous task in science and engineering.

Acknowledgements:

The experiment was carried out in University of Science and Technology of China (Shanghai), Prof. Haohua's group in Zhejiang University, and Prof. Dongning's group in Institute of Physics Chinese Academy of Sciences. The theory was done by Prof. Yuxi's group in Tsinghua University, Prof. Changpu's group in China Beijing Computational Science Research Center, Prof. William J. Munro in NTT Basic Research Laboratories and Prof. Kae Nemoto in National Institute of Informatics. The sample fabrication is supported by the micro-fabrication lab on IOP-China, National Center for Nanoscience and Technology and USTC.

Superconducting Circuit QED for Quantum Annealing, Computing, and Simulation

Jaw-Shen Tsai

RIKEN / Tokyo University of Science

In this talk, our circuit schemes towards quantum annealing, quantum computing, and quantum simulation are described where circuit QEC is actively employed. In the quantum annealing, a qubit coupling scheme using resonator is considered. Cluster state quantum computing and boson sampling are also discussed.

IBM Quantum Experience

Hanhee Paik

IBM T J Watson Research Center, Yorktown Heights, NY 10598 USA

In 2016, IBM established, for the first time, a cloud-based superconducting quantum computing system for research and education: the IBM Quantum Experience [1], which allows the community to create and run small quantum algorithms. We recently launched a 16-qubit device on the cloud as a new Quantum Experience system, which can be accessed via a API. I will demonstrate the control and interface, and discuss our ongoing effort towards scaling up the quantum hardware.

[1] https://quantumexperience.ng.bluemix.net.

The shortcut-to-adiabaticity and its application to quantum computation

Shi-Liang Zhu

Nanjing University

Accurate control of a quantum system is a fundamental requirement in many areas of modern science ranging from quantum information processing to high-precision measurements, while adiabatic approach is one of essential tools to this end. For examples, Stimulated Raman adiabatic passage (STIRAP) is a robust way to realize high-fidelity state transfer in physics and beyond, and adiabatic dynamics plays a key role in adiabatic geometric quantum computation. However, these applications are limited by the requirement of slow driving, and thus some adiabatic schemes are not realizable when the decoherence time of a quantum system is short. Therefore, speeding up an adiabatic process would be significantly important in the applications of these adiabatic protocols. In this talk, I will present our recent work on the shortcuts to adiabaticity. In the first example, I will present a shortcut-to-adiabatic protocol to speed-up the STIRAP. By modifying the shapes of the Raman pulses, we theoretically proposed and then experimentally realized a fast and high-fidelity stimulated Raman shortcut-to-adiabatic passage that is robust against control parameter variations. In my second example, I will present a feasible scheme to implement a universal set of quantum gates based on geometric phases and the shortcut-to-adiabaticity. Consolidating the advantages of both strategies, the proposed quantum gates are robust and fast, which is confirmed by comparing the fidelities of several kinds of phase gates.

[1] Y. X. Du, Z. T. Liang, Y. C. Li, X. X. Yue, Q. X. Lv, W. Huang, X. Chen, H. Yan, and S. L. Zhu, Nature Communications 7, 12479 (2016).

[2] Z. T. Liang, X. Yue, Q. Lv, Y. X. Du, W. Huang, H. Yan, and S. L. Zhu, Physical Review A 93, 040305(R).

[3] Y. X. Du, X. X. Yue, Z. T. Liang, J. Z. Li, H. Yan, and S. L. Zhu, Phys. Rev. A 95, 043608 (2017).

Quantum simulation and dynamical quantum phase transition with superconducting circuits

Lin Tian

University of California, Merced

Rich controllability and long decoherence times make superconducting quantum devices promising candidates for scalable quantum computing and quantum simulation. Here I'll present our recent works on analog quantum simulators built with superconducting qubits and microwave resonators. In particular, I will discuss the dynamical quantum phase transition of a quantum simulator coupled to a cavity mode and the dynamics of the sudden phase switchings in this system.

Quantum chemistry using superconducting qubits

Michael Marthaler and Frank Wilhlem-Mauch

Karlsruher Institut für Technologie

We discuss the prospects of using near term processor containing 50 to 100 superconducting qubit to do quantum chemistry or to perform ab-initio simulation of materials. At present, the overhead for quantum error correction is so large that it cannot be implemented for near term quantum computers. This means applications have to be planned with the limitation imposed by decoherence in mind. Even while considering decoherence, quantum chemistry offers a relatively clear path towards useful applications, since the implementation of simulation algorithms on a quantum computer is comparatively straight forward.

We consider a situation where the quantum computer is used to simulate fermionic problems, as this is in general the goal of quantum chemistry. We discuss how the qubit layout can be optimized, for the simulation of specific models. We show that many sources of decoherence act on such a simulator, in way that is quite similar to perturbations acting on the fermionic system we are simulating. As an example, pure dephasing, takes the form of electron-phonon coupling in our simulation.

Nonlinearity in superconducting circuits

Tiefu Li

1. *Institute of Microelectronics, and Tsinghua National Laboratory of Information Science and Technology, Tsinghua University, 100084 Beijing, China.*
2. *Quantum Physics and Quantum Information Division, Beijing Computational Science Research Center, 100193 Beijing, China.*
3. *RIKEN Center for Emergent Matter Science (CEMS), 2-1 Hirosawa, Wako, Saitama 351-0198, Japan.*

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Nonlinearity in superconducting circuits can give many interesting and useful phenomena. Here we report two experiments in superconducting circuits with strong and ultrastrong nonlinearities. First, the design and characterization of a controllable frequency comb generated in a tunable superconducting resonator in microwave regime will be presented. Both the combs' center frequency and the teeth density are precisely controllable. The teeth spacing can be adjusted from Hz to MHz. Experimental results are well explained with the theoretical analysis. Then, the experimental observation of high-order sideband transitions at the single-photon level in a circuit QED system of a flux qubit ultrastrongly coupled to a coplanar waveguide resonator will be discussed. With the coupling strength reaching 10% of the resonator's fundamental frequency, we obtain clear signatures of higher-order red- and first-order blue-sideband transitions. These transitions are owing to the ultrastrong Rabi coupling, instead of the driving power. Our observation advances the understanding of ultrastrongly-coupled systems.

Higher Symmetry Kondo effect in Quantum Dots

Guoping Guo

Key Laboratory of Quantum Information, University of Science and Technology of China, Chinese Academy of Sciences, Hefei 230026, China

Kondo effect is an essential many-body physics dealing with the screening of a spin impurity by a sea of conduction electron. Quantum dot (QD) is a perfect platform to study the fundamental property of Kondo effect for two reasons [1]: 1 An electronic island coupled to two metallic leads is a direct concretization of spin impurity Kondo theory model. 2 Parameters and spin impurity number can be manipulated precisely in QD system.

Other momentum, such as orbital, can play the role of pseudo-spin as well. Here we report an experiment observation of orbital-spin Kondo effect in a series GaAs double QDs system with a clear predicted three Kondo peaks [2]. The orbital degree of freedom arise from the orbital occupation of one or other dot. Furthermore under special electrical field the three Kondo peaks converges to single Kondo peak whose higher TK and splitting evolution under magnetic field provide an evidence for an emerging orbital-spin SU(4) symmetry [see Fig.1]. Also, we will report a novel four-peak Kondo effect in an electrical capacitive coupled GaAs double QDs (quadruple dots) [3].

Besides GaAs system we observed Kondo effect in a graphene double QDs, in a quantum electrodynamics hybrid circuit environment. A quantized pi-phase shift occurs at low temperatures in the reflected light signal until large bias scales is indeed a strong signature of Kondo physics in agreement with theory. The presence of orbital and spin entanglement in the mesoscopic device tends to support a Kondo state with spin-orbital SU(4) symmetry [4].

[1] D. Goldhaber-Gordon et al. Nature, 391,156 (1998).
[2] Runan Shang et al. under preparation for submitting
[3] Runan Shang et al. Phys.Rev.B, 91,245102(2015)
[4] Guangwei Deng et al. arXiv:1509.06141(2015)

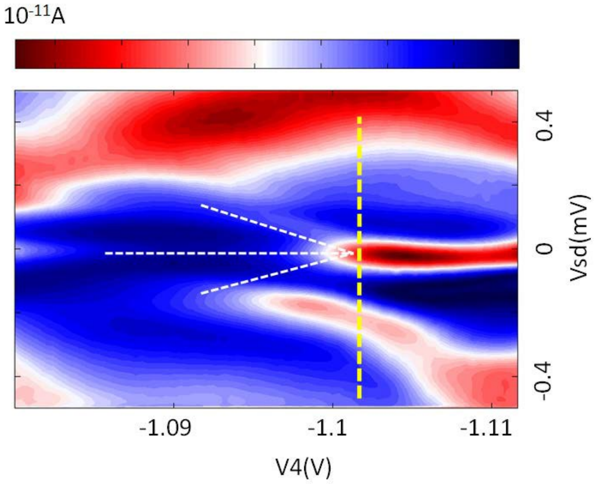

Fig. 1 A three Kondo peaks to one Kondo peak transition.

Long-time entanglement logarithm growth for many-body localization in a superconducting quantum processor

Heng Fan

Institute of Physics, Chinese Academy of Sciences

Many-body localization may exist for quantum systems with both interactions and disorder, differing from Anderson localization which is only for noninteracting particles. The disorder and interactions, resulting in many-body localized state, prevent the system from evolving quickly to a thermalized state implying equilibrium in the whole system. For finite isolated quantum many-body system, one critical evidence of many-body localization is the long-time entanglement entropy logarithm growth characterizing slow time evolution for localized state. The direct observation of it is still elusive due to challenging in experiment. Here, we report the observation of entanglement logarithm growth for many-body localization in a ten-qubit superconducting quantum processor. Other evidences, such as imbalance, single-site occupation, entropy volume law and properties of entanglement are also presented to confirm occurring of many-body localization and thermalization, respectively. Our results lay solid foundations for simulating precisely physics of quantum many-body systems in platform of large-scale multi-qubit superconducting quantum processor.

Color code quantum computation with Majorana bound states*

Felix von Oppen

Freie Unversität Berlin

We establish color codes as providing a natural setting in which advantages offered by topological hardware can be combined with those arising from topological error-correcting software for full-fledged fault-tolerant quantum computing. Most importantly, color codes have a set of transversal gates which coincides with the set of topologically protected gates in Majorana-based systems, namely the Clifford gates. We illustrate our scheme by providing a complete description of a possible architecture based on topological superconductor networks. Hexagonal cells serve as physical qubits, which allow for a direct implementation of open-boundary color codes with ancilla-free syndrome readout and logical T-gates via magic state distillation.

[*] D. Litinski, M. S. Kesselring, J. Eisert, F. von Oppen, *Combining Topological Hardware and Topological Software: Color Code Quantum Computing with Topological Superconductor Networks,* arXiv:1704.01589 (2017).

Majorana zero mode in the vortex of an artificial topological superconductor

Yaoyi Li

Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China Collaborative Innovation Center of Advanced Microstructures, Nanjing 210093, China

Majorana zero modes, which behave like Majorana fermions, are quasiparticle excitations in condensed matter systems. They obey non-Abelian statistics, and have been proposed as building blocks of topological quantum computers. They are predicted to exist in the vortex of topological superconductors. In 2012, such a topological superconductor was engineered by depositing topological insulator thin films on top of an s-wave superconductor. Thereafter, several evidences have been reported to prove the MZMs' existence in the vortex. In this talk, by putting all experimental and theoretical results together, we show that these experimental evidences are self-consistent and they are also strongly supported by the theories, so the existence of MZM is firmly established. Moreover, the adjacent MZMs annihilate when two vortices are close enough, which demonstrate that they have the nature of Majorana fermions. Finally, their potential application in topological quantum computing is discussed.

Topological superconducting devices made from semiconductor nanostructures

Hongqi Xu

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Topological superconducting systems are intriguing physical systems in which an elusive class of fermions—Majorana fermions, whose antiparticles are themselves, can be created and can be used to construct topological qubits for quantum computing. Here I report the realization and quantum transport measurements of topological superconducting quantum devices made from semiconductor nanostructures. The talk will be divided into two parts. In the first part, our study of topological superconducting quantum devices made from InSb nanowires and s-wave Sb superconductors will be reported and discussed. In each of the devices, a quantum dot is fabricated between two topological superconducting InSb nanowires. Both a zero conductance peak arising from Majorana fermions located at two outer ends of the two nanowires and two side conductance peaks arising from the interaction between the two inner Majorana fermions in the vicinity of the quantum dot are observed. In the second part of my talk, our very recent work on topological quantum devices made from InSb nanoplates and s-wave Al superconductors will be reported and discussed. Here, I will show that it is possible to turn the semiconductor InSb nanoplates into two-dimensional topological insulators. As a consequence, in a Josephson junction made from an InSb nanoplate in the topological phase, the measured supercurrent as a function of magnetic field shows an interference pattern which is in accordance with the transport through the edges of the nanoplate. Finally, future directions of the field and perspective applications of topological superconducting quantum devices in the quantum information technology will be discussed.

Majorana Zero Modes in Semiconductor Nanowires

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Majorana modes are zero-energy excitations of a topological superconductor that exhibit non-Abelian statistics. To fully exploit the non-Abelian properties for topological quantum computing, Majorana modes first need to be experimentally fully established. Then these modes can be exchanged in a well-controlled braiding operation, which requires nanowire networks coupled to superconducting islands. Here we report great progress achieved in both directions, i.e. new Majorana evidence and nanowire network systems for braiding circuits, as discussed below.

Disorders can mimic the zero-energy Majorana signatures, and render the topological properties inaccessible. We show substantial reduction of disorders in our Majorana devices, by observing clear ballistic transport, together with a stable Majorana zero bias conductance peak (ZBCP). These advances not only exclude alternative explanations that invoke disorder, but also increase the ZBCP height towards the predicted universal quantized value, a unique signature of Majoranas which directly stems from its topological property.

A basic requirement for certain measurement-based braiding schemes is phase coherent transport through a nanowire network system for Majorana qubit readout. We demonstrate this by observing clear Aharonov-Bohm (AB) oscillations in our nanowire network loop structure. In addition, we developed a new technique to growth superconductor islands on these nanowire networks epitaxially. These superconducting islands induce a hard superconducting gap in the nanowire networks which can survive until 1 Tesla, surpasses the field value for a topological phase transition.

[1] H. Zhang*, O, Gul*, et al, arXiv:1603.04069

[2] S. Gazibegovic*, D. Car*, H. Zhang*, et al, arXiv:1705.01480

Quantum anomalous Hall system as a platform to study topological quantum computation

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The quantum anomalous Hall (QAH) effect is a quantum Hall effect induced by spontaneous magnetization instead of an external magnetic field. The effect occurs in two-dimensional (2D) insulators with topologically nontrivial electronic band structure characterized by a non-zero Chern number. In thin films of magnetically doped $(Bi,Sb)_2Te_3$ topological insulators (TIs), the QAH effect was experimentally observed. The chiral edge states in absence of magnetic field of a QAH system, combined with superconducting states, can be used to create and detect chiral Majorana modes and to realize topological quantum computation. I will introduce our efforts on improving the QAH materials for higher temperature and less magnetic disorder and discuss what should be done next for experiments on Majorana modes based on QAH states.

Resistance of the edge mode of a 2D topological insulator

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We investigate the influence of nuclear spins on the resistance of helical edge states of two-dimensional topological insulators (2DTIs). Via the hyperfine interaction, nuclear spins allow electron backscattering, otherwise forbidden by time reversal symmetry. We identify two backscattering mechanisms, depending on whether the nuclear spins are ordered or not. Their temperature dependence is distinct, but both give resistance which increases with the edge length, decreasing temperature, and increasing strength of the electron-electron interaction. Overall, we find that the nuclear spins will typically shut down the conductance of the 2DTI edges at zero temperature.

[1] Ch.-H. Hsu, P. Stano, J. Klinovaja, D. Loss, Nuclear spin-induced localization of the edge states in two-dimensional topological insulators, arxiv:1703.03421

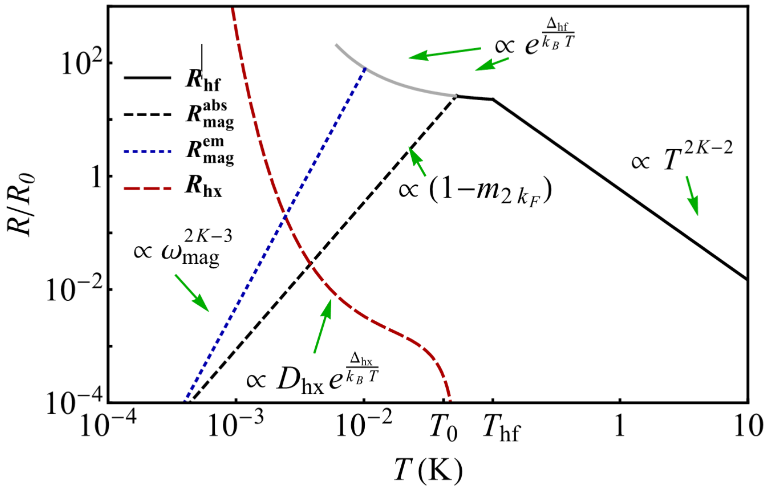

Fig 1: Resistance as a function of temperature.

Search for Majorana zero modes in rf-SQUIDs constructed on Bi_2Se_3 surface

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Recently, much attention has been paid to search for Majorana zero modes in solid-state systems. Among various searching proposals there is a long-sought experiment, in which radio-frequency superconducting quantum interference devices (rf-SQUIDs) are proposed to create the π phase difference required for hosting the Majorana zero modes in Josephson junctions constructed on topological insulator-related materials. In this talk, I will report the observations of a 4π-period-like but truncated current-phase relation on rf-SQUIDs constructed on the surface of three-dimensional topological insulator Bi_2Te_3. Our results reveal the existence of a fractional mode on the rf-SQUIDs, supporting the occurrence of Majorana zero modes in these devices.

[1] Y. Pang, et al., arXiv:1503.00838v2.

Diamond Quantum Devices: From Quantum Simulation to Hyperpolarised Magnetic Resonance Imaging

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The numerical simulation of strongly correlated quantum many-body systems especially in two spatial dimensions can become intractable for as few as about 100 particles. Quantum simulators offer a route to overcome this computational barrier, but currently proposed realizations of quantum simulators either require extreme conditions such as low temperature/ultra-high vacuum and/or are difficult to scale to the required sizes. Here, we propose a new solid-state architecture for a scalable quantum simulator that consists of strongly interacting nuclear spins on the surface of diamond. Initialization, control and read-out of this quantum simulator can be accomplished with shallow nitrogen-vacancy (NV) centers in diamond [1]. The system can be engineered to simulate a wide variety of strongly correlated spin models and, owing to the excellent coherence properties of nuclear spins and NV-centers, it offers a new route towards large-scale quantum simulation at ambient conditions. Work towards the experimental realization of the initialization of the quantum simulator [2] that I will present here has resulted, as a by-product, in new methods for the hyperpolarization of nuclear spins external to diamond by means of optically pumped NV-centers in diamond [3]. These techniques may result in application as diverse as submicron-scale NMR or metabolic cancer imaging in MRI. I will also report on our recent work on the development of new dynamical decoupling sequences that allow for the control of nuclear spin quantum registers in the vicinity of NV centers in diamond for the purposes of quantum simulation and quantum computation [4, 5].

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Trapped ion system for molecular spectroscopy

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Factorization or boson sampling [1] is a problem that quantum computers are expected to solve more efficiently than conventional computers. The boson sampling is considered to demonstrate the superiority of a quantum computer with less resources than Shor’s factorization algorithm, which requires the full capacity of quantum computation. Serious experimental endeavors have been reported to realize the boson sampling problem in a small quantum system toward beyond the classical limitation. Recently, it has been pointed out that a type of the boson sampling problem, a continuous variable version of the problem [2,3], can be applied to sample the vibration spectrum of a molecule beyond simply showing the excellence of a quantum computer [4,5]. Here, we present the first experimental demonstration that this vibronic spectrum is sampled in a quantum device with the example of SO$_2$. Different from other boson sampling demonstrations, we realize the sampling with phonons in a trapped ion system, which can be more favorable for the large scale implementation [6,7]. In our realization, the molecular scattering operation is decomposed to a series of elementary quantum optical operations, which are implemented through Raman laser beams, resulting in a multimode Gaussian (Bogoliubov) transformation. The molecular spectroscopic signal is reconstructed from the collective projection measurements on phonon modes through the coupling to the internal degree of freedom. Our experimental demonstration would pave the way to large-scale molecular quantum simulations, which are classically intractable.

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