1st INTERNATIONAL SYMPOSIUM ON TRANS-SCALE QUANTUM SCIENCE

TSQS 2021

ABSTRACT BOOK

OCTOBER 25-29, 2021, JST ONLINE CONFERENCE

ORGANIZED BY THE UNIVERSITY OF TOKYO Trans-Scale Quantum Science Institute

SPONSORED BY JSR Corporation

ABOUT THE 1ST INTERNATIONAL SYMPOSIUM ON TRANS-SCALE QUANTUM SCIENCE (TSQS2021)

TSQS2021 is a part of the Trans-Scale Quantum Science Institute's activities to bring together world-leading scientists from various branches of physics, and to create opportunities for interdisciplinary discussions on recent discoveries and possible future developments. We hope to provide all participants with a holistic perpective of the present and future of quantum science, and each lecture will cover its respective topic from its fundamentals to the most recent advances. To finish every session, we plan a panel discussion session where we expect lively interactions between the audience and the speakers, who will discuss interdisciplinary topics of interest with specialists and non-specialists alike. We sincerely hope that students, people from the industry and academics will benefit from this symposium, and we are looking forward to everyone's active participation.

We wish to extend our thanks to all participants, and to JSR Corporation for sponsoring this event.

Organizing committee
TSQS2021
Trans-Scale Quantum Science Institute
The University of Tokyo

INVITED SPEAKERS

James G. Analytis
University of California Berkeley, USA

N. Peter Armitage
Johns Hopkins University, USA

Immanuel Bloch
Ludwig Maximilian University of Munich, Germany

Collin Broholm
Johns Hopkins University, USA

Andrea Cavalleri
Max Planck Institute, Germany

Kohei Itoh
Keio University, Japan

Dmitri Kharzeev
Stony Brook University, USA

Debbie Leung
University of Waterloo, Canada

Allan MacDonald
The University of Texas at Austin, USA

Hitoshi Murayama
University of California, Berkeley, USA

Kae Nemoto
National Institute of Informatics, Japan

Hidetoshi Nishimori
Tokyo Institute of Technology, Japan

Hirosi Ooguri
Kavli IPMU, The University of Tokyo, Japan & California Institute of Technology, USA

Shinsei Ryu
Princeton University, USA

Subir Sachdev
Harvard University, USA

Eiji Saitoh
The University of Tokyo, Japan

Hidenori Takagi
Max Planck Institute, Germany & The University of Tokyo, Japan

Yoshinori Tokura
RIKEN & The University of Tokyo, Japan

Masahito Ueda
The University of Tokyo, Japan

Ashvin Vishwanath
Harvard University, USA

Jun'ichi Yokoyama
The University of Tokyo, Japan

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- Please make sure that your audio is set to "Mute", and your video feed is off when you join the Conference Zoom.
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- The allotted time for panel discussions is of 30 minutes for two-speaker panels, and 45 minutes for three-speaker panels.
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- When the session begins, please switch on your audio and video feeds.
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- When a presentation is finished, please switch on your audio feed, and proceed with the discussion following the presentation. If an attendee has raised their hand (by Zoom gestures), prompt them by name to state their question. Questions might be written in the chat. In this case, please read out loud the question.

PROGRAM (all times JST)

Day 1

Mon, Oct 25, 2021
08:00-13:50 (JST)

08:00-08:15	**Opening Remarks** Satoru Nakatsuji (U. Tokyo, Japan)
SESSION 1	Chair: Masaki Oshikawa (U. Tokyo, Japan)
08:15-09:05	**TBD** Hitoshi Murayama (UC Berkley, USA)
09:05-09:55	**Entanglement dynamics of quantum many-body systems: quasi-particle v.s. membrane pictures** Shinsei Ryu (Princeton U., USA)
09:55-10:45	**Completeness of gauge charges in quantum gravity** Hirosi Ooguri (Kavli IPMU, U. Tokyo, Japan & Caltech, USA)
10:45-11:30	**Panel Discussion**
SESSION 2	Chair: Masamitsu Hayashi (U. Tokyo, Japan)
11:40-12:30	**Spintronics in magnetic topological insulators** Allan MacDonald (UT Austin, USA)
12:30-13:20	**Quasi particles and coherence in nano systems** Eiji Saitoh (U. Tokyo, Japan)
13:20-13:50	**Panel Discussion**

Day 2

Tue, Oct 26, 2021
08:00-11:15 (JST)

SESSION 3	Chair: Masao Ogata (U. Tokyo, Japan)
08:00-08:50	**Kitaev interactions in Co based quantum magnets** N. Peter Armitage (Johns Hopkins U., USA)
08:50-09:40	**Low-power, long-range spin transfer in frustrated magnets and other correlated systems** James G. Analytis (UC Berkeley, USA)
09:40-10:30	**Chirality and quantum information** Dmitri Kharzeev (Stony Brook U., USA)
10:30-11:15	**Panel Discussion**

Day 3

Wed, Oct 27, 2021
15:00-19:30 (JST)

SESSION 4	Chair: Kensuke Kobayashi (U. Tokyo, Japan)
15:00-15:50	**Probing quantum matter in- and out-of equilibrium on a large-scale atomic quantum simulator** Immanuel Bloch (LMU Munich, Germany)
15:50-16:40	**Beyond-Hermitian quantum physics** Masahito Ueda (U. Tokyo, Japan)
16:40-17:10	**Panel Discussion**
SESSION 5	Chair: Ryusuke Matsunaga (U. Tokyo, Japan)
17:20-18:10	**Driven quantum materials** Andrea Cavalleri (MPI Hamburg, Germany)
18:10-19:00	**Quantum spin liquid with fractionalized excitations-make it real!** Hidenori Takagi (MPI Stuttgart, Germany & U. Tokyo, Japan)
19:00-19:30	**Panel Discussion**

PROGRAM (all times JST)

Day 4

Thu, Oct 28, 2021
08:00-12:30 (JST)

SESSION 6	Chair: Chair: Mio Murao (U. Tokyo, Japan)
08:00-08:50	**Quantum computing algorithms and software** Kohei Itoh (Keio U., Japan)
08:50-09:40	**Quantum channel capacities** Debbie Leung (U. Waterloo, Canada)
09:40-10:10	**Panel Discussion**

SESSION 7	Chair: Mio Murao (U. Tokyo, Japan)
10:20-11:10	**Quantum simulation by quantum annealing** Hidetoshi Nishimori (TIT, Japan)
11:10-12:00	**Quantum computer designs from today's NISQ processors to tomorrow's fault-tolerant quantum computers** Kae Nemoto (NII, Japan)
12:00-12:30	**Panel Discussion**

Day 5

Fri, Oct 29, 2021
08:00-13:40 (JST)

SESSION 8	Chair: Satoru Nakatsuji (U. Tokyo, Japan)
08:00-08:50	**Emergent electromagnetic responses from topological magnets** Yoshinori Tokura (RIKEN & U. Tokyo, Japan)
08:50-09:40	**Emergent quasi-particles in frustrated magnets** Collin Broholm (Johns Hopkins U., USA)
09:40-10:10	**Panel Discussion**

SESSION 9	Chair: Kenji Fukushima (U. Tokyo, Japan)
10:20-11:10	**A simple model of many-particle entanglement: how it describes black holes and superconductors** Subir Sachdev (Harvard U., USA)
11:10-12:00	**Quantum aspects of inflationary cosmology** Jun'ichi Yokoyama (U. Tokyo, Japan)
12:00-12:50	**Correlations and topology in twisted structures** Ashvin Vishwanath (Harvard U., USA)
12:50-13:35	**Panel Discussion**
13:35-13:40	**Closing Remarks** Masahito Ueda (U. Tokyo, Japan)

Day 1

Monday, October 25, 2021

08:15-09:05 **Opening Remarks**
Satoru Nakatsuji (U. Tokyo, Japan)

SESSION 1 Chair: Masaki Oshikawa (U. Tokyo, Japan)

08:15-09:05 **TBD**
Hitoshi Murayama (UC Berkley, USA)

09:05-09:55 **Entanglement dynamics of quantum many-body systems: quasi-particle v.s. membrane pictures**
Shinsei Ryu (Princeton U., USA)

09:55-10:45 **Completeness of gauge charges in quantum gravity**
Hirosi Ooguri (Kavli IPMU, U. Tokyo, Japan & Caltech, USA)

10:45-11:30 **Panel Discussion**

SESSION 2 Chair: Masamitsu Hayashi (U. Tokyo, Japan)

11:40-12:30 **Spintronics in magnetic topological insulators**
Allan MacDonald (UT Austin, USA)

12:30-13:20 **Quasi particles and coherence in nano systems**
Eiji Saitoh (U. Tokyo, Japan)

13:20-13:50 **Panel Discussion**

SESSION 1 | 08:15-09:05

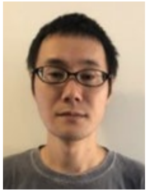
Supersymmetry as a tool to study quantum systems

Hitoshi Murayama
University of California, Berkeley, LBNL, USA &
Kavli IPMU, The University of Tokyo, Japan

Supersymmetry is a symmetry in quantum field theory that can interchange bosons and fermions. It provides powerful control over the dynamics of strongly correlated systems which in some cases allows for exact solutions. To approach realistic systems, however, supersymmetry needs to be broken. I discuss how supersymmetry can be broken in a specific way to preserve the exact solutions [1]. I use non-abelian gauge theories as an example of application of this method, to understand properties such as confinement and chiral symmetry breaking [2].

[1] H. ayama, *Phys. Rev. Lett.* **126** 25, 251601 (2021)
[2] C. Csáki et al https://arXiv.org/abs/2106.10288

Entanglement dynamics of quantum many-body systems: quasi-particle v.s. membrane pictures



Shinsei Ryu
Princeton University, USA

Quantum many-body systems can exhibit rich and complex dynamical behaviors. Loosely speaking, we can distinguish at least two types of dynamics. Integrable systems retain the information of initial states during time-evolution. On the other hand, non-integrable or “chaotic” systems completely forget initial states – they thermalize at late times. In this talk, we explore different types of quantum dynamics by looking at how quantum information and quantum entanglement propagate. In particular, we try to classify different entanglement dynamics by different effective descriptions, the quasi-particle and membrane pictures. Specifically, we discuss how the scaling behaviors of various entanglement measures (entanglement entropy, mutual information, and reflected entropy, etc.) detect integrable or chaotic dynamics and how they can be captured by the effective descriptions.

SESSION 1 | 09:55-10:45

Completeness of gauge charges in quantum gravity

Hirosi Ooguri

Kavli IPMU, The University of Tokyo, Japan &
California Institute of Technology, USA

After reviewing my earlier proofs of the absence of global symmetries and the completeness hypothesis in consistent quantum theory in the context of the AdS/CFT correspondence, I present a derivation of a simple formula for the density of black hole microstates which transform in each irreducible representation of any finite gauge group. Since each representation appears with nonzero density, this gives a new proof of the completeness hypothesis for finite group gauge symmetries. Inspired by the generality of the argument we further propose that the formula applies at high energy in any quantum field theory with a finite-group global symmetry, and give some evidence for this conjecture.

SESSION 1 | 11:40-12:30

Spintronics in magnetic topological insulators

Allan MacDonald

The University of Texas at Austin, USA

Spintronics is the study of the interplay between electrical transport properties and magnetic properties in magnetically ordered conductors – both magnetic configuration control of electrical properties and electrical control of magnetic properties – and has applications in magnetic information storage technology. I will discuss the properties of magnetic topological insulators like $MnBi_2Te_4$, and their potential role in future spintronics. Most of my discussion will be framed in terms of a simplified coupled Dirac-cone model [1] that captures many qualitative features in a remarkably simple way. $MnBi_2Te_4$ thin films can exhibit a quantum anomalous Hall effect [2] even in thin films that have no spin magnetism [3], and by virtue of their strong spin-orbit coupling open up many new opportunities for electrical control of magnetic configurations. Among these I will focus mainly on the possibility of establishing electrical reservoirs for magnons.

[1] C. Lei, S. Chen, and A. H. MacDonald, *PNAS* **117**, 27224-27230 (2020)

[2] C. Lei et al., *Phys. Rev. Mater.* **5**, 064201 (2021)

[3] C. Lei, and A. H. MacDonald, *Phys. Rev. Mater.* **5**, L051201 (2021)

Quasi particles and coherence in nano systems

Eiji Saitoh
The University of Tokyo, Japan

Various excitations in solids are described in terms of quasi particles such as electrons, phonons, and magnons; based on the concept of quasi-particles, atomistic and mechanical understandings of material properties have been constructed. On the other hand, electron and nuclear spins give birth to pseudo-conservation of angular momentum, which has brought about various spintronics functions. The rediscovery of spin currents carried by quasi particles has made it possible to directly observe the angular momentum transport in solids, and various material functions driven by spin current have been found. By using spin current, the interference between the quasi particles can also be realized in a controllable way, and recently it has become possible to extract microscopic information of solids from the interference. In this talk, we will give an overview of spintronics physics from the perspective of quasiparticles and their interference.

[1] E. Saitoh, M. Ueda, and H. Miyajima, *Appl. Phys. Lett.* **88**, 182509 (2006)
[2] K. Uchida et al., *Nature* **455**, 778-781 (2008)
[3] Y. Kajiwara et al., *Nature* **464**, 262-266 (2010)
[4] R. Takahashi et al., *Nature Physics* **12**, 52-56 (2016)
[5] Y. Shiomi et al., *Nature Physics* **15**, 22–26 (2019)

Day 2

Tuesday, October 26, 2021

SESSION 3 Chair: Masao Ogata (U. Tokyo, Japan)

08:00-08:50 **Kitaev interactions in Co based quantum magnets**
N. Peter Armitage (Johns Hopkins U., USA)

08:50-09:40 **Low-power, long-range spin transfer in frustrated magnets and other correlated systems**
James G. Analytis (UC Berkeley, USA)

09:40-10:30 **Chirality and quantum information**
Dmitri Kharzeev (Stony Brook U., USA)

10:30-11:15 **Panel Discussion**

SESSION 3 | 08:00-08:50

Kitaev interactions in Co based quantum magnets

N. Peter Armitage
Johns Hopkins University, USA

Kitaev quantum spin liquids (QSLs) are exotic states of matter that are predicted to host Majorana fermions and gauge flux excitations. However, so far all known Kitaev QSL candidates are known to have appreciable non-Kitaev interactions that pushes these systems far from the QSL regime. Co-based magnets have been proposed to be perhaps a more ideal platform for realizing Kitaev QSLs. In this talk I will show evidence for a Kitaev interactions in both the quasi-one-dimensional ferromagnet $CoNb_2O_6$ as well as the hexagonal magnet $BaCo_2(AsO_4)_2$. $CoNb_2O_6$ was believed to be the best material realization of a 1D Ising chain, showing evidence for a 1+1 D quantum critical point and Kramers-Wannier duality. We have recently shown that that $CoNb_2O_6$ is well described a model with bond-dependent interactions that we call the 'twisted Kitaev chain', as these interactions are similar to those of the honeycomb Kitaev spin liquid. The ferromagnetic ground state of $CoNb_2O_6$ arises from the compromise between two axes. Owing to this frustration, even at zero, field domain walls have quantum motion, which is described by the celebrated Su–Schriefer–Heeger model of polyacetylene and shows rich behaviour as a function of field. Most recently, we have shown that the honeycomb cobalt-based Kitaev QSL candidate, $BaCo_2(AsO_4)_2$, has dominant Kitaev interactions. Due to only small non-Kitaev terms a magnetic continuum consistent with Majorana fermions and the existence of a Kitaev QSL can be induced by a small out-of-plane-magnetic field. Our results $BaCo_2(AsO_4)_2$ as a far more ideal version of Kitaev QSL compared with other candidates. If time allows, I will also discuss our efforts to not just measure these materials spectroscopically, but also control them with ultrafast THz pulses, which opens up a number of possibilities for quantum information processing and control.

[1] J. Steinberg et al., *Phys. Rev. B* **99**, 035156 (2019)
[2] C.M. Morris et al., *Nature Physics* **17**, 832–836 (2021)
[3] X. Zhang, et al., https://arxiv.org/abs/2106.13418

SESSION 3 | 08:50-09:40

Low-power, long-range spin transfer in frustrated magnets and other correlated systems

James G. Analytis
University of California, Berkeley, USA

Research into new methods to control magnetic spin textures has been largely focused on technological applications. However, complex magnets, particularly those characterized by magnetic frustration, offer opportunities for ultra-low power applications. This is due to two main characteristics of such systems: 1) the nearly degenerate phase space of magnetic states available to such systems, and 2) novel magneto-electric coupling available to these materials. In this work, we illustrate unusual mechanisms for spin transfer are available to such strongly correlated systems, revealing potential opportunities for applications of quantum materials.

SESSION 3 | 09:40-10:30

Chirality and quantum information

Dmitri Kharzeev
Stony Brook University and BNL, USA

Chirality is a common theme in many branches of modern science, from particle physics to cosmology. In quantum physics, chirality plays an especially important role due to the chiral structure of the Standard Model that is responsible for parity violation in weak interactions. The chiral anomaly describes the transfer of chirality between chiral fermions and gauge fields, and enables a new type of dissipation-free quantum transport that has been observed in condensed matter systems and is currently under study in the quark-gluon plasma. These phenomena may allow a new generation of quantum devices. Also, the absence of dissipation in the anomalous transport has a simple interpretation in the language of quantum information.

Day 3

Wednesday, October 27, 2021

SESSION 4	Chair: Kensuke Kobayashi (U. Tokyo, Japan)
15:00-15:50	**Probing quantum matter in- and out-of equilibrium on a large-scale atomic quantum simulator** Immanuel Bloch (LMU Munich, Germany)
15:50-16:40	**Beyond-Hermitian quantum physics** Masahito Ueda (U. Tokyo, Japan)
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17:20-18:10	**Driven quantum materials** Andrea Cavalleri (MPI Hamburg, Germany)
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Day 3
Wednesday
Oct 27, 2021

SESSION 4 | 15:00-15:50

Probing quantum matter in- and out-of equilibrium on a large-scale atomic quantum simulator

Immanuel Bloch
Ludwig Maximilian University of Munich, Germany

More than 30 years ago, Richard Feynman outlined his vision of a quantum simulator for carrying out complex calculations on physical problems. Today, his dream has become a reality in laboratories around the world. Ultracold atoms trapped in optical lattices provide a particular intriguing setting for realising such quantum simulators with the possibility to control and detect the systems down to the level of single atoms on single lattice sites. In my talk, I will discuss select applications for such neutral atom quantum simulators to probe quantum phases of strongly interacting electronic systems, including hidden magnetic order, topological phases as well as non-equilibrium dynamics that provide new paradigms for statistical physics. I will discuss the status of the field and give an outlook on future scalability of the systems.

SESSION 4 | 15:50-16:40

Beyond-Hermitian quantum physics

Masahito Ueda
The University of Tokyo, Japan

Beyond-Hermitian quantum physics has attracted a great deal of attention in many subfields of physics due to remarkable advances in experimental techniques and theoretical methods in AMO, condensed matter and nonequilibrium statistical physics [1]. A full knowledge of types and occurrence times of quantum jumps allows a complete description of quantum trajectories. A subclass thereof without quantum jumps can be described by a non-Hermitian Hamiltonian. Here symmetries, topological properties and many-body effects of Hermitian physics are fundamentally altered. Transposition and complex conjugation, which are equivalent in Hermitian physics, become inequivalent in the non-Hermitian framework, leading to nontrivial topological phases [2] through unification and ramification of topological phases [3] and resulting in 38 symmetry classes instead of 10 in the Altland-Zirnbauer classification [4]. In random matrices, transposition symmetry leads to two new universality classes of level-spacing statistics other than the Ginibre ensemble [5]. In many-body physics, non-hermiticity leads to the dynamical sign reversal of magnetic correlations in dissipative Hubbard models [6] and anomalous g-theorem-violating reversion of renormalization-group flows in the Kondo problem [7].

[1] Y. Ashida, et al., *Adv. Phys.* **69**, 249 (2020).
[2] Z. Gong, et al., *Phys. Rev. X* **8**, 031079 (2018).
[3] K. Kawabata, et al., *Nat. Commun*. **10**, 297 (2019).
[4] K. Kawabata, et al., *Phys. Rev. X* **9**, 041015 (2019).
[5] R. Hamazaki, et al., *Phys. Rev*. *Research* **3**, 023286 (2020).
[6] M. Nakagawa, et al., *Phys. Rev. Lett*. **124**, 147203 (2020).
[7] M. Nakagawa, et al., *Phys. Rev. Lett*. **121**, 203001 (2018).

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Day 3
Wednesday
Oct 27, 2021

SESSION 5 | 17:20-18:10

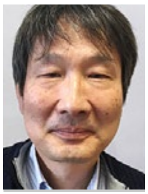
Driven quantum materials

Andrea Cavalleri
Max Planck Institute, Hamburg, Germany

In this paper I will discuss the use of far infrared radiation to drive collective modes of solids, and how this opens up many new opportunities to manipulate the functional properties of quantum materials. I will discuss how such functional control can be achieved in superconductors, ferroelectrics, magnets and topological materials.

SESSION 5 | 18:10-19:00

Quantum spin liquid with fractionalized excitations- make it real!



Hidenori Takagi
Max Planck Institute, Stuttgart, Germany &
The University of Tokyo, Japan

In conventional magnetic materials, interactions between the spins lead to a phase transition from a high-temperature disordered state to a magnetically ordered state as the temperature is lowered. The transition is typically accompanied by singularities in the thermodynamic observables at the transition point, and spontaneous symmetry breaking and a reduction of the spin entropy to zero as the system enters a unique ground state. However, the spin entropy can also be released without any symmetry breaking, down to zero temperature, by forming a collective quantum spin state with long-range quantum entanglement. This exotic state of matter is called a quantum spin liquid. A goal of condensed matter physics is to discover new quantum phases formed by the ensemble of interacting spins and charges in solids. The QSL is perhaps one of the most exotic quantum phases known so far partly because of the nontrivial elementary excitations and has been attracting the attention of condensed matter scientists for several decades.

In 2006 a theoretical breakthrough in the field of QSLs was reported. Alexei Kitaev proposed a simple new model that is exactly solvable and that gives a QSL ground state, in which the spins fractionalize into emergent quasiparticles — Majorana fermions [1]. Soon after, a spin-orbital $J_{eff} = 1/2$ Mott insulator was identified in a complex 5d iridium oxide. This led to a theoretical proposal for the realization of the Kitaev model using $J_{eff} = 1/2$ pseudo-spins in an iridate and initiated a search for the QSL state and the hidden Majorana fermions in a family of iridium and ruthenium compounds [2]. I am going to talk about the rapid progress in the materialization Kitaev QSL as well as the hunting of Majorana fermions through the detection of chiral edge state.

[1] A. Kitaev, Ann. *Phys*. **321**, 2-111 (2006)
[2] H.Takagi et al., *Nat. Rev. Phys*. **1**, 264–280 (2019)

Day 4

Thursday, October 28, 2021

SESSION 6 — Chair: Mio Murao (U. Tokyo, Japan)

08:00-08:50 **Quantum computing algorithms and software**
Kohei Itoh (Keio U., Japan)

08:50-09:40 **Quantum channel capacities**
Debbie Leung (U. Waterloo, Canada)

09:40-10:10 **Panel Discussion**

SESSION 7 — Chair: Mio Murao (U. Tokyo, Japan)

10:20-11:10 **Quantum simulation by quantum annealing**
Hidetoshi Nishimori (TIT, Japan)

11:10-12:00 **Quantum computer designs from today's NISQ processors to tomorrow's fault-tolerant quantum computers**
Kae Nemoto (NII, Japan)

12:00-12:30 **Panel Discussion**

SESSION 6 | 08:00-08:50

Quantum computing algorithms and software

Kohei M. Itoh
Keio University, Japan

Rapid advancement of quantum computer hardware calls for development of quantum computing algorithms and software that can contribute to the advancement of science, engineering, and industry. Intuitively, quantum computers should exhibit significant advantage when simulating objects are governed by the law of quantum mechanics rather than classical mechanics. Such examples include simulation of atomic and molecular states, chemical reaction, etc. Other directions involve utilization of the quantum parallelism leading to simultaneous calculations involving seemingly infinite combinations. The present talk introduces recent advances in quantum computing algorithms and software developed at Keio University Quantum Computing Center.

SESSION 6 | 08:50-09:40

Quantum channel capacities

Debbie Leung
University of Waterloo, Canada

A quantum channel transmits a quantum state from a sender to a receiver, and can be used to communicate various types of data (quantum, private, or classical) from the sender to the receiver, or to share entanglement between them. Noisy quantum channels model the most general lossy quantum dynamics. When a noisy quantum channel is used repeatedly in a memoryless manner, a quantum error correcting code can be used to perform one of these tasks with less error but at a reduced rate; the ultimate rate is called the capacity of the channel for the task.

In this talk, we will summarize major results in quantum channel capacities. Then, we focus on various surprising quantum phenomena caused by entanglement between different channel uses, resulting in high communication rates deemed implausible under reasonable assumptions (for example, superadditivity, superactivation, and privacy without coherence). The talk will be based on pedagogical results in the subject, joint work with Felix Leditzky, Ke Li, Vikesh Siddhu, Graeme Smith, and John Smolin, and some open problems.

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Day 4
Thursday
Oct 28, 2021

SESSION 7 | 10:20-11:10

Quantum simulation by quantum annealing

Hidetoshi Nishimori
Tokyo Institute of Technology, Japan

Quantum annealing was designed to solve combinatorial optimization problems. Recent years have seen its further developments in quantum simulation, i.e., to simulate the properties of materials under strong quantum effects. I first review a few important contributions in this rapidly-developing field and then explain our results on the non-equilibrium quantum dynamics in the one-dimensional transverse-field Ising model in the context of the Kibble-Zurek mechanism [1]. Also discussed is the limit of simulability of quantum dynamics by simulated quantum annealing, a classical stochastic algorithm, which is often used as an alternative tool of quantum annealing [2].

[1] Y. Bando et al., *Phys. Rev. Res.* **2**, 033369 (2020)
[2] Y. Bando, and H. Nishimori, *Phys. Rev. A* **104**, 022607 (2021)

SESSION 7 | 11:10-12:00

Quantum computer designs from today's NISQ processors to tomorrow's fault-tolerant quantum computers

Kae Nemoto
National Institute of Informatics, Japan

In the last decade, we have seen the emergence of small-scale quantum computers commonly referred as NISQ processors. These quantum computational hardware developments have stimulated research into software technologies. This has given us the opportunity now to consider software layers for quantum computer technologies, however the validity and scalability of these technologies are still in question. In this talk, we explore the pros and cons of these NISQ processors. We will further discuss possibilities for small-scale quantum computers outside of the realm of today's NISQ processors. The technologies developed for NISQ processors brought the coherent controllability of various quantum systems, which will open new opportunities in both quantum physics and quantum computation. Finally, we will discuss the scalability of these quantum systems and identify the key challenges we face as we move forward towards fault-tolerant quantum computers.

[1] M. P. Estarellas et al., *Sci. Adv*. **6**, eaay8892 (2020)
[2] M. Gong, et al., *Science* **372** (6545), 948-952 (2021)
[3] K. Nemoto et al., *Phys. Rev. X* **4**, 031022 (2014)

Day 5

Friday, October 29, 2021

SESSION 8 Chair: Satoru Nakatsuji (U. Tokyo, Japan)

08:00-08:50 **Emergent electromagnetic responses from topological magnets**
Yoshinori Tokura (RIKEN & U. Tokyo, Japan)

08:50-09:40 **Emergent quasi-particles in frustrated magnets**
Collin Broholm (Johns Hopkins U., USA)

09:40-10:10 **Panel Discussion**

SESSION 9 Chair: Kenji Fukushima (U. Tokyo, Japan)

10:20-11:10 **A simple model of many-particle entanglement: how it describes black holes and superconductors**
Subir Sachdev (Harvard U., USA)

11:10-12:00 **Quantum aspects of inflationary cosmology**
Jun'ichi Yokoyama (U. Tokyo, Japan)

12:00-12:50 **Correlations and topology in twisted structures**
Ashvin Vishwanath (Harvard U., USA)

12:50-13:35 **Panel Discussion**

13:35-13:40 **Closing Remarks**
Masahito Ueda (U. Tokyo, Japan)

SESSION 8 | 08:00-08:50

Emergent electromagnetic responses from topological magnets

Yoshinori Tokura
RIKEN & The University of Tokyo, Japan

The topology of spin texture either in momentum space and real space can generate emergent electromagnetic fields acting on the conduction and valence electrons in solid, produce intriguing properties and responses. One archetypical example is magnetic topological insulators, in which the spin-momentum locking as well as the magnetization-induced mass-gap shows up to form the ideal Weyl (spin-momentum locked) fermion system at surface. With control of the magnetizations on the top and bottom surfaces, quantum anomalous Hall state and quantum magnetoelectric (axion insulator) state can be realized. One other important example of topological magnets is a magnetic skyrmion, which forms real-space spin-swirling texture with integer winding number. Its real-space topology protects the skyrmion from external perturbations, realizing a robust metastable state. Novel electromagnetic phenomena arise from the topological spin textures, such as huge topological Hall effect (via Berry curvature) and emergent electromagnetic induction (via temporal Berry connection). These momentum-space or real-space topological spin textures are overviewed with perspectives of exploration for new quantum materials and functions.

SESSION 8 | 08:50-09:40

Emergent quasi-particles in frustrated magnets*

Collin Broholm
Johns Hopkins University, USA

Crystalline solids with Interacting local moments that do not fully order at low temperatures can support a variety of strongly correlated electronic phenomena. With no static magnetism or symmetry breaking, the quantum spin liquid (QSL) represents an important albeit rare limit. A much larger variety of materials has been found to have spin liquid like properties in restricted temperature and frequency regimes. I shall describe experiments that explore such materials by scattering neutrons from their emergent magnetic quasi-particles. The materials range from insulating rare earth oxides through transition metal oxides near the metal insulator transition to Kondo semi-metals and heavy fermions systems. Conducted using the latest neutron scattering instrumentation, the experiments offer detailed atomic scale insights into strongly correlated phenomena that challenge conventional understanding of magnetism in solids.

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SESSION 9 | 10:20-11:10

A simple model of many-particle entanglement: how it describes black holes and superconductors

Subir Sachdev
Harvard University &
Institute for Advanced Studies, Princeton, USA

Entanglement is the strangest feature of quantum theory, often dubbed ''spooky action at a distance''. Quantum entanglement can occur on a macroscopic scale with trillions of electrons, leading to new forms of matter with properties of technological importance. Related entanglement structures arise across black hole horizons, giving rise to Hawking's information puzzle. I will describe the Sachdev-Ye-Kitaev model of many-particle entanglement which has shed light on these distinct fields of physics [1,2,3].

[1] S. Sachdev and J. Ye, *Physical Review Letters* **70**, 3339 (1993)
[2] S. Sachdev, *Physical Review Letters* **105**, 151602 (2010)
[3] A. Kitaev, Talks at KITP Santa Barbara (2015)

SESSION 9 | 11:10-12:00

Quantum aspects of inflationary cosmology

Jun'ichi Yokoyama
The University of Tokyo, Japan

Four decades after its original proposal, inflationary expansion in the early Universe is now regarded as an indispensable ingredient of modern standard cosmology which not only explains fundamental properties of the global spacetime of our universe, namely, why our universe is so large, so homogeneous, and so old with full of matters, but also account for the origin of tiny density and curvature perturbations that eventually grow to all the cosmic structures we observe today [1]. The latter owes to quantum physics in the early universe; microphysical quantum fluctuations or zero-point oscillation of the scalar field responsible for inflation is stretched to cosmological scales by virtue of exponential expansion of the background space. Observations of the cosmic microwave background radiation, which is a fossil of the Universe at the time of photon-baryon decoupling, 380 thousand years after the Big Bang, reveal good agreement with the prediction of standard inflationary cosmology. To single out the right theory in high energy physics responsible for inflation from these observations is one of the ultimate goals of the studies on inflationary cosmology. Recently we have calculated one-loop correction to the power spectrum of curvature perturbations generated during inflation and found a nontrivial constraint on the propagation speed of these fluctuations [2], which may be helpful to further constrain model building.

[1] K. Sato, and J. Yokoyama, *Int. J. Mod. Phys*. **D24**, 1530025 (2015)
[2] J. Kristiano, and J. Yokoyama, https://arXiv.org/abs/2104.01953

SESSION 9 | 12:00-12:50

Correlations and topology in twisted structures

Ashvin Vishwanath
Harvard University, USA

I will discuss recent progress in understanding correlated phases, including superconductivity, in magic angle graphene, from a topological and quantum geometric viewpoint [1]. A spectacular application of these concepts predicts a fractional Chern insulator in graphene at certain fillings, which is borne out by recent experiments [2]. Finally, I will discuss twisted structures built out of correlated materials. In particular, I will review our recent results on a t-J model approach to twisted bilayer cuprates, and prospects for acquiring new insights into the old problem of doped Mott insulators using twisted structures [3].

[1] P. J. Ledwith, E. Khalaf, and A. Vishwanath, https://arXiv.org/abs/2105.08858
[2] Y. Xie et al., https://arXiv.org/abs/2107.10854
[3] X.-Y. Song, Y.-H. Zhang, and A. Vishwanath, https://arXiv.org/abs/2109.08142

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The Trans-Scale Quantum Science Institute was established on February 1st, 2020 with the objective of forming a research platform encompassing all scales of quantum science, including cosmology, particle physics, condensed matter physics, quantum information and mathematics. The creation of the Institute was based on the observation that recent discoveries have come about by introducing ideas from branches of physics that are unrelated at first glance. For instance, topological gauge-field theories proposed in high energy physics are now recognized as models for topological phases in matter such as quantum Hall systems, and are drawing attention as a promising platform for fault tolerant quantum computation and quantum memory. Another example is that of Weyl fermions, which had been introduced as a model of neutrinos and were discovered in solid-state materials recently, leading to the development of novel high-speed memory.

With this in mind, we aim to drive innovation by fostering interdisciplinary research and leveraging the active interplay between multiple areas to make experimental discoveries, formulate novel theories and create concepts and fields that encompass physics of various scales. Moreover, we aim to make an impact on society by pushing forward the development of future technologies, and by training young talent to master quantum science at various levels and equip them with the necessary skills to continue the long-term development of these technologies.

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Trans-Scale Quantum
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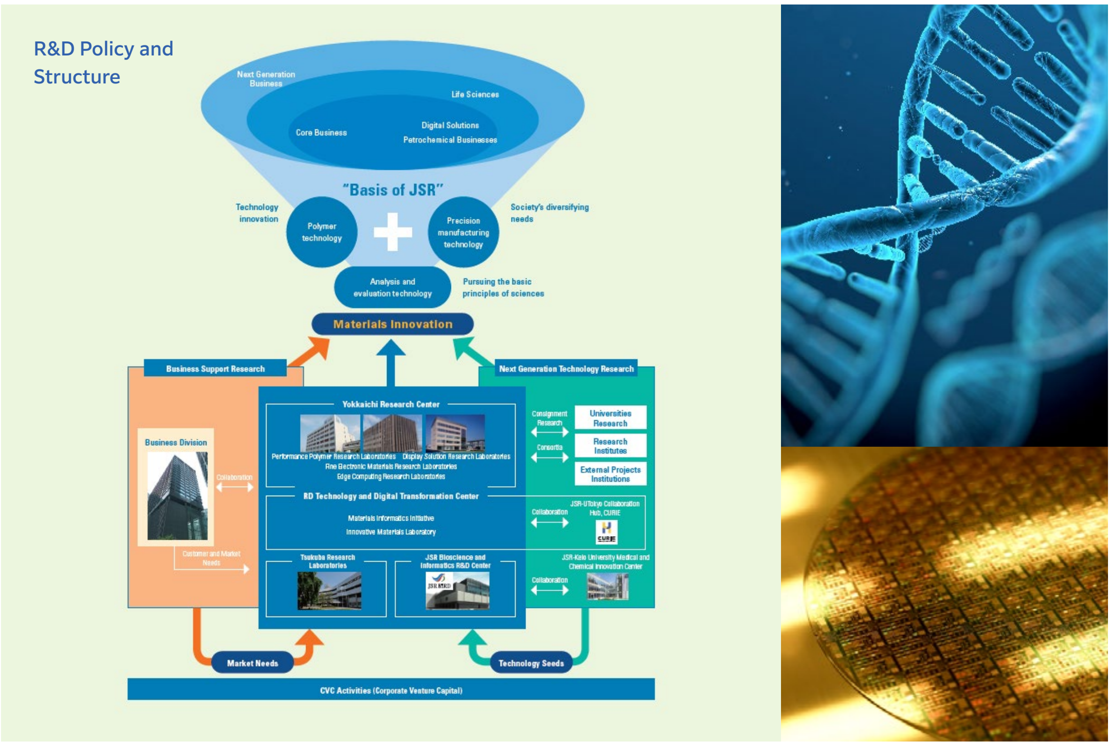

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