TSQS

2ND INTERNATIONAL SYMPOSIUM ON TRANS-SCALE QUANTUM SCIENCE

TSQS 2022 HYBRID CONFERENCE

ABSTRACT BOOK

GREETING

TSQS2022 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 perspective of the present and future of quantum science, and each talk will cover its respective topic from its fundamentals to the most recent advances.

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
TSQS2022
Trans-Scale Quantum Science Institute
The University of Tokyo

Plenary Speakers

Anne Broadbent
University of Ottawa

Christian Degen
ETH Zürich

Nuh Gedik
Massachusetts Institute of Technology

Philipp Höhn
Okinawa Institute of Science and Technology Graduate University

Brad Marston
Brown University

Brad Ramshaw
Cornell University

Sanjay Reddy
University of Washington

Tadashi Takayanagi
Kyoto University

Invited Speakers

Masamitsu Hayashi
The University of Tokyo

Akito Kusaka
The University of Tokyo

Takeshi Kondo
The University of Tokyo

Ryusuke Matsunaga
The University of Tokyo

Mio Murao
The University of Tokyo

Takashi Oka
The University of Tokyo

Shinji Tsuneyuki
The University of Tokyo

Satoshi Yamamoto
The University of Tokyo

Masahito Yamazaki
The University of Tokyo

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GENERAL INFORMATION FOR ON-SITE PARTICIPANTS

COVID-19 Countermeasures

The TSQS2022 organizers are committed to welcoming participants into a safe environment and ensuring their safe return home.
We appreciate the kind understanding and cooperation of all participants.

Before participation

- We recommend all participants to be vaccinated at least three times or be tested negative (PCR or antigen test) within three days before participation. Submission of certificate documents is not required.

At the entrance

- When you arrive at the reception desk, please use hand sanitizer to disinfect your hands, take your temperature and bring your name tag. Your body temperature will be monitored by the automatic thermometer at the reception desk.
- If you have COVID19-like symptoms, such as fever, you will not be allowed to enter the conference room.

Masks

- Wearing a non-woven mask is mandatory in the venue, except in designated areas and occasions.
- Non-woven masks are provided at the reception desk in case you forget to bring your own ones.

Disinfection

- The session and poster rooms are equipped with hand sanitizer. Please use hand sanitizer to disinfect your hands.

Non-alcoholic beverages

- Non-alcoholic beverages are allowed in the venue.

Venue access information

Bldg.1 #234, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN
The reception desk is in front of Koshiba Hall, Bldg.1.

Below are the links to the map:

- https://www.u-tokyo.ac.jp/content/400020133.pdf
- https://www.s.u-tokyo.ac.jp/en/map/map02.html
- https://www.s.u-tokyo.ac.jp/en/map/map01.html

Opening hours of the venue

- Day 1 : Tuesday, November 8	9:00-18:00
- Day 2 : Wednesday, November 9	9:00-17:00
- Day 3 : Thursday, November 10	9:00-18:00
- Day 4 : Friday, November 11	9:00-15:00

Poster awards

Poster award winners will be selected from poster presentations submitted from students and postdoctoral researchers. The selection is based on the presenters' performance in the poster sessions.

General information

- Please come to the Koshiba Hall for talk sessions.
- When you ask a question, please speak in front of the microphone on the floor.
- In poster sessions, please come to the poster session room at any time during the conference and discuss with presenters.
- Secretariat contact information (Email: secretariat@tsqs2022.org)
- Conference staffs may take pictures for reporting purposes during the conference.

INSTRUCTIONS FOR REMOTE AUDIENCE

- Please mute microphone and turn off video when you join the Conference Zoom.
- Please set “First-name Last-name (Affiliation)” as your Zoom screen name. Example: Taro Yamada (The University of Tokyo).
- Please do not record still screenshots, videos, or audios of the presentations to respect authorship rights.
- To pose a question during the discussion time, please first use the “Raise Hand” feature in Zoom. When selected by the session chair, please unmute and turn on your video. After finishing the question, please mute and switch off your video.
- The meeting host may remotely mute or switch off the video of participants.

INSTRUCTIONS FOR ORAL PRESENTERS

- Please come to the room of the session at least 10 minutes before the session starts to test laptop and microphone connection. The Zoom meeting room will be open 15 minutes before the session begins.
- On-site presenters need to ensure that their laptop can be connected to HDMI cables (VGA connection is not available).
- The allotted time for oral presentations is as follows:
  - Plenary talks: 30-minute presentation followed by 10 minutes of discussion;
  - Invited talks: 20-minute presentation followed by 5 minutes of discussion;
  - Contributed talks: 12-minute presentation followed by 3 minutes of discussion.

INSTRUCTIONS FOR POSTER PRESENTERS

Poster session schedule:

Two poster session will be held at the lobby in front of the Koshiba Hall and room 337c.

- Poster session 1: November 8 15:00-17:00
- Poster session 2: November 10 15:00-17:00

The size of the poster board is W900 mm x H1800 mm.

On-site participation:

- Please print and set up your poster on the assigned poster board before the session starts. Pins will be provided for poster mounting. The poster board will be available from 12:00 pm on the first day of the session.
- During your assigned session, please stand by your poster to receive attendee questions and comments. You will be disqualified from the poster award competition if you do not present the poster during the assigned poster session.
- Please remove your poster from the board at the end of each session. The conference secretariat will dispose any remaining posters after 18:30 for poster session 1 and 18:00 for poster session 2. The secretariat will assume no responsibility for those posters.

INSTRUCTIONS FOR SESSION CHAIRS

- Please come to the Chairperson’s seats at least 5 minutes before the session starts. The Zoom meeting room will be open 15 minutes before the session begins.
- At the beginning of each presentation, please introduce the presenter and the presentation title.
- Please explain the time allocation at the beginning of the session and ensure each presenter adheres to the time limit.
- When a presentation is finished, please proceed with the discussion. When attendees raise hand via the Zoom function, call their names shown on the Zoom screen to allow them asking questions.

PROGRAM [all times JST]

DAY 1 TUESDAY, NOVEMBER 8, 2022

09:30-09:50	**Opening Remarks** Satoru Nakatsuji (U. Tokyo) and Hiroaki Tokuhisa (JSR)

SESSION 1 QUANTUM GRAVITY AND PARTICLE THEORY

Chair: A. Kusaka (U. Tokyo)

09:50-10:30 Plenary	**A New Generalization of Entanglement Entropy** Tadashi Takayanagi (Kyoto U.)
10:30-11:10 Plenary	**Quantum frame covariance** Philipp Höhn (OIST)
11:10-11:35 Invited	**Theoretical Engineering of Integrable Models from Extra Dimensions** Masahito Yamazaki (U. Tokyo)
11:35-11:50 Contributed	**Complexity Equal Anything** Shan-Ming Ruan (Kyoto U.)
11:50-13:20	**Lunch**

SESSION 2 SPINTRONICS AND ENTANGLEMENT

Chair: K. Kobayashi (U. Tokyo)

13:20-14:00 Plenary	**Quantum sensing of nanoscale magnetic phenomena** Christian Degen (ETH)
14:00-14:25 Invited	**Spin currents and light-spin interaction in Dirac materials** Masamitsu Hayashi (U. Tokyo)
14:25-14:40 Contributed	**Accurate magnetic field imaging with nanodiamond quantum sensors enhanced by machine learning** Kento Sasaki (U. Tokyo)
14:40-15:00	**Coffee Break**
15:00-17:00	**Poster Session 1** Chair: M. Murao (U. Tokyo)

DAY 2 WEDNESDAY, NOVEMBER 9, 2022

SESSION 3 QUANTUM INFORMATION

Chair: P. Höhn (OIST)

09:30-10:10 Plenary	**Quantum Unclonability and Cryptography** Anne Broadbent (U. Ottawa)
10:10-10:35 Invited	**Universally superposing quantum operations toward quantum functional programming** Mio Murao (U. Tokyo)
10:35-10:50 Contributed	**Universal trade-off structure between symmetry, irreversibility, and quantum coherence in quantum processes** Hiroyasu Tajima (U. Electro-Communications)
10:50-11:10	**Coffee Break**

SESSION 4 HIGH-T_c AND BEYOND

Chair: S. Nakatsuji (U. Tokyo)

11:10-11:50 Plenary	**The Planckian Limit in Strange Metals** Brad Ramshaw (Cornell U.)
11:50-12:15 Invited	**Unveiling doped Mott states of high-T_c cuprate superconductors** Takeshi Kondo (U. Tokyo)
12:15-12:40 Invited	**Theoretical Exploration of Hydride Superconductors** Shinji Tsuneyuki (U. Tokyo)
12:40-12:55 Contributed	**Strange universe in correlated quantum matter driven by entanglement between multipoles and conduction electrons** Mingxuan Fu (U. Tokyo)
12:55-13:05	**Group Photo**
13:05-17:00	**Free Discussion**

DAY 3 THURSDAY, NOVEMBER 10,2022

SESSION 5 ASTROPHYSICS AND COSMOLOGY
Chair: K. Fukushima (U. Tokyo)

09:30-10:10 Plenary	**Extreme quantum matter in neutron stars and its implications for multi-messenger astrophysics** Sanjay Reddy (U. Washington)
10:10-10:35 Invited	**Chemical View of Star and Planet Formation** Satoshi Yamamoto (U. Tokyo)
10:35-11:00 Invited	**Exploration of Inflation and Dark Universe through Cosmic Microwave Background** Akito Kusaka (U. Tokyo)
11:00-11:20	**Coffee Break**

SESSION 6 TOPOLOGICAL PHENOMENA
Chair: M. Oshikawa (U. Tokyo)

11:20-12:00 Plenary	**Waves of Topological Origin in the Fluid Earth System** Brad Marston (Brown U.)
12:00-12:15 Contributed	**Detection and manipulation of topological responses in the Weyl antiferromagnet Mn_3Sn** Tomoya Higo (U. Tokyo)
12:15-12:30 Contributed	**Metrology of Band Topology via Resonant Inelastic x-ray Scattering** Sangjin Lee (Inst. Basic Science)
12:30-14:00	**Lunch**
14:00-15:00	**Panel Discussion** Facilitator: Mingxuan Fu (U. Tokyo)
15:00-17:00	**Poster Session 2** Chair: M. Hayashi (U. Tokyo)

DAY 4 FRIDAY, NOVEMBER 11, 2022

SESSION 7 NONEQUILIBRIUM AND EMERGING PARTICLES
Chair: R. Shimano (U. Tokyo)

09:30-10:10 Plenary	**Ultrafast Charge Order Dynamics in a Kagome Metal** Nuh Gedik (MIT)
10:10-10:35 Invited	**Floquet engineering and topological nonlinear optics** Takashi Oka (U. Tokyo)
10:35-11:00 Invited	**Terahertz anomalous Hall effect dynamics in Weyl antiferromagnet** Ryusuke Matsunaga (U. Tokyo)
11:00-11:15 Contributed	**Theoretical studies of photoinduced topological phase transitions in organic salt α-$(BEDT\text{-}TTF)_2I_3$** Keisuke Kitayama (U. Tokyo)
11:15-11:45	**Best Poster Award & Closing Remarks** Jun'ichi Yokoyama (U. Tokyo)

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Wen Si Tokyo Institute of Technology	Substrate-induced Broken C4 Symmetry and Gap Variation in Superconducting Monolayer FeSe/$SrTiO_3$ - /13 ×/13	PS1-03
Takachika Isomae The University of Tokyo	Unsaturated Large Magnetoresistance in the Quadrupolar Kondo Lattice System $PrTi_2Al_{20}$	PS1-04
Ryo Kainuma Tokyo Institute of Technology	Magnon-polariton in multiferroic $BiFeO_3$	PS1-05
Kouki Yamamoto The University of Tokyo	Nanodiamond quantum thermometer assisted with machine learning	PS1-06
Eria Imada The University of Tokyo	NMR study on Bose-Einstein condensation under magnetic fields in quasi-two-dimensional antiferromagnet $YbCl_3$	PS1-07
Akifumi Mine The University of Tokyo	Direct observation of the superconducting gap in the topological superconductor $PdBi_2$ by low-temperature and high-resolution laser ARPES	PS1-08
Yuto Kinoshita The University of Tokyo	Field-induced re-Insulation in the extreme quantum state of a topological insulator $Bi_{1-x}Sb_x$ (x~0.1)	PS1-09
Hiroki Matsumoto The University of Tokyo	Cavity magnetomechanics of surface acoustic waves with a synthetic antiferromagnet	PS1-10
Takuya Takashiro The University of Tokyo	Soft-magnetic skyrmions induced in a sandwich structure with intrinsic ferromagnetic topological insulators	PS1-11
Yoshua Hirai The University of Tokyo	Circularly polarized light-induced terahertz anomalous Hall effect of three-dimensional Dirac electrons in bismuth	PS1-12
Kazuma Ogawa The University of Tokyo	All-optical switching of chirality and magnetization in ferromagnetic Weyl semimetal Co_3Sn2S_2	PS1-13
Seyed Reza Ghazanfari The University of Tokyo	Cubic ferromagnet and its emergent phenomenon in the vicinity of phase boundary	PS1-14
Kouta Kondou RIKEN	Magnetic spin Hall effect and its spin-orbit torque in a topological Wely antiferromagnet	PS1-15
Kouta Kondou RIKEN	Investigation of magnetic octupole domain wall dynamics in a topological antiferromagnet	PS1-16
Ibuki Taniuchi The University of Tokyo	Circular photogalvanic effect in surface superstructures on Si(111) with huge Rashba-splittings	PS1-17
Masahiko Yunokizaki The University of Tokyo	Fabrication of sub-micron size MTJ device.	PS1-18
Takuya Matsuda The University of Tokyo	Extreme nonequilibrium states in strongly-correlated Weyl antiferromagnet studied by terahertz spectroscopy	PS1-19
Zili Feng The University of Tokyo	Giant and Robust ANE in a Polycrystalline Topological Ferromagnet Fe_3Ga	PS1-20
Yuki Amari The University of Tokyo	CP^2 Skyrmion crystals in an SU(3) magnet with a generalized Dzyaloshinskii-Moriya interaction	PS1-21
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Kouhei Fukai The University of Tokyo	The local conserved quantities of open spin-1/2 XYZ chain	PS1-23
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Akito Sakai The University of Tokyo	Heavy fermion multigap superconductivity in the ferroquadrupole ordered state of $PrTi_2Al_{20}$	PS2-03
Shunichiro Kurosawa The University of Tokyo	Detail investigation on the relation between the magneto-transport properties and the chiral anomaly in the Weyl antiferromagnet Mn_3Sn	PS2-04
Takumi Matsuo The University of Tokyo	Preferred orientation and improved interfaces in sputtered Mn_3Sn/Ta films	PS2-05
Xiaoni Zhang The University of Tokyo	Electronic topological transition of 2D boron by the ion exchange reaction	PS2-06
Ryosuke Hirakida The University of Tokyo	The Chirality-dependent second-order spin current in systems with time-reversal symmetry	PS2-07
Ryota Akiyama The University of Tokyo	Growth of atomically flat topological crystalline insulator SnTe(001) thin films using the room temperature wetting layer method and its electrical transport measurements	PS2-08
Shoya Sakamoto The University of Tokyo	Giant orbital polarization at the Fe/MgO interface probed by depth-resolved x-ray magnetic circular dichroism	PS2-09
Ryotaro Sano Kyoto University	Breaking down the magnonic Wiedemann-Franz law in the hydrodynamic regime	PS2-10
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Toshiya Ikenobe The University of Tokyo	Unusual Superconductivity in the Nodal-Line Semimetal NaAlSi	PS2-12
Hanyi Peng The University of Tokyo	Large magneto-optical Kerr effect in polycrystalline Mn_3Sn thin films	PS2-13
Yuta Murotani The University of Tokyo	Light-induced anomalous Hall effect in 3D Dirac semimetal Cd_3As_2 revealed by THz spectroscopy	PS2-14
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Yuto Fukushima The University of Tokyo	Observation of unoccupied states and topological characterization of Bi(111)	PS2-21
Hiroto Nakamura The University of Tokyo	Observation of logarithmic anomaly in the transverse thermoelectric conductivity at low temperature in ferromagnet CoMnSb	PS2-22
Shunsuke Sato The University of Tokyo	Development of the simultaneous measurement system of four-point-probe electrical transport and tunneling spectroscopy	PS2-23
Kensuke Yoshida The University of Tokyo	Experimental Study of Surface States in Superfluid Helium 3-B phase	PS2-24
Mihiro Asakura The University of Tokyo	Physical properties of polycrystalline Mn_3Sn films deposited by molecular beam epitaxy	PS2-25
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Wei-Lin Tu Korea University	Tensor network ansatz for the quantum many-body models	PS2-28
Yuki Koike The University of Tokyo	Effects of Mn-doping in Mn_3Sn on the Phase Transitions and Transport Properties near Criticality	PS2-29
Hiroyasu Koizumi University of Tsukuba	Schrödinger representation of quantum mechanics, Berry connection, and superconductivity	PS2-30
Jason Kristiano The University of Tokyo	One-loop perturbativity bound in single-field inflation	PS2-31
Shutaro Shimamura The University of Tokyo	Foliated-exotic duality in fractonic BF theories	PS2-32
Shinichiro Yahagi The University of Tokyo	Conformal field theories and error correcting codes	PS2-33
Rurie Mizuno The University of Tokyo	Measurement of muon-induced nuclear transmutation for Si isotopes.	PS2-34
Kyosuke Ishito Tokyo Institute of Technology	Truly chiral phonons in α-HgS	PS2-35
Shoki Koyanagi Kyoto University	Numerically “exact” simulation of quantum Carnot cycle: Dynamics and thermodynamics	PS2-36
Alexey Vylegzhanin Okinawa Institute of Science and Technology Graduate University	Rydberg Atom Interactions with an Optical Nanofiber	PS2-37
Hayata Yamasaki The University of Tokyo	Time-Efficient Constant-Space-Overhead Fault-Tolerant Quantum Computation	PS2-38
Satoshi Yoshida The University of Tokyo	Reversing unknown qubit-unitary operation, deterministically and exactly	PS2-39
Shunsuke Kamimura University of Tsukuba	Universal Scaling Bounds on a Quantum Heat Current	PS2-40

DAY 1

TUESDAY,
NOVEMBER 8, 2022

Opening Remarks

Satoru Nakatsuji (U. Tokyo) and
Hiroaki Tokuhisa (JSR)

SESSION 1

QUANTUM GRAVITY AND PARTICLE THEORY

Chair: A. Kusaka (U. Tokyo)

SESSION 2

SPINTRONICS AND ENTANGLEMENT

Chair: K. Kobayashi (U. Tokyo)

Poster Session 1

Chair: M. Murao (U. Tokyo)

A New Generalization of Entanglement Entropy

PLENARY SPEAKERS

Tadashi Takayanagi

Yukawa Institute for Theoretical Physics, Kyoto University

Holographic Principle argues that a gravitational theory in a certain spacetime is equivalent to a quantum many-body system which lives on its boundary. This idea provides a simple geometric computation of entanglement entropy. This generalizes the well-known Bekenstein-Hawking formula of black hole entropy and strongly suggests that a gravitational spacetime consists of many bits of quantum entanglement. After we give a brief review of this field, I will explain progresses on a recently introduced quantity called pseudo entropy, which generalizes the entanglement entropy such that it depends on both the initial and final state [1,2]. This quantity has a manifest geometric dual via holography. Moreover, this can also serve as a new quantum order parameter which can distinguish different quantum phases [3].

[1] Y. Nakata, T. Takayanagi, Y. Taki, K. Tamaoka and Z. Wei, Phys. Rev. D **103** (2021) 026005.

[2] I. Akal, T.Kawamoto, S. M. Ruan, T. Takayanagi and Z. Wei, Phys. Rev. D 105 (2022) 126026.

[3] A. Mollabashi, N. Shiba, T. Takayanagi, K. Tamaoka and Z. Wei, Phys. Rev. Lett. **126** (2021) 081601; Phys. Rev. Res. **3** (2021) 033254.

Quantum frame covariance

PLENARY SPEAKERS

Philipp Höhn

Okinawa Institute of Science and Technology

Quantum reference frames are reference frames associated with quantum systems. Since these can be in relative superposition, a fascinating question is how one can transform between the descriptions of a given physical situation relative to different choices of such quantum reference frames. Can one establish a quantum frame covariance that translates between the different internal perspectives that quantum systems may have on one another? In this talk, I will address these questions and explain how recent developments constitute a quantum extension of classical relativity principles. This leads to a quantum frame dependence of the very notion of subsystems and thereby to a quantum relativity of correlations, superpositions and thermal properties. Time permitting, I will discuss implications for gauge theories and gravity.

Theoretical Engineering of Integrable Models from Extra Dimensions

INVITED SPEAKERS

Masahito Yamazaki

Kavli IPMU, The University of Tokyo

Integrable models are a special class of physical systems that have enough conserved charges and hence can be solved exactly. They provide invaluable data for e.g. understanding critical phenomena in condensed matter systems, and are useful stepping stones for analyzing generic non-integrable/chaotic systems.

In the past few years, a new framework has emerged to explain many of the existing results, as well as new ones, from a certain four-dimensional Chern-Simons-type quantum field theory. While we are interested in theories in two spacetime dimensions, it is useful to include two extra dimensions and consider everything from the four-dimensional perspective. The geometries of the extra dimensions are rich enough to "theoretically engineer" a class of integrable models and uncover their properties.

As an example of these results, we explain how to better understand relations between integrable lattice models and integrable quantum field theories, where the latter can be regarded as the low-energy limit of the former. Such studies are useful for the quantum simulation of two-dimensional integrable quantum field theories, and potentially for benchmarking noisy quantum devices in the future. Our discussion is "T-dual" to the relation between knot theory and the three-dimensional Chern-Simons theory, which relation is the theoretical basis for the topological quantum computation.

[1] K. Costello, E. Witten and M. Yamazaki, ICCM Not. 6, 46-119 (2018), arXiv:1709.09993 [hep-th]
[2] K. Costello and M. Yamazaki, arXiv:1908.02289 [hep-th]

Complexity Equal Anything

CONTRIBUTED SPEAKERS

Shan-Ming Ruan

Yukawa Institute for Theoretical Physics, Kyoto University

We expand on our results in [1] to present a broad new class of gravitational observables in asymptotically Anti-de Sitter space living on codimension-zero regions of the bulk spacetime. These new observables display two key universal features [2]: they grow linearly in time at late times and reproduce the switchback effect. Hence we argue that any member of this new class of observables is an equally viable candidate as a gravitational dual of complexity. Further, using the Peierls construction, we show that variations of both the codimension-zero and codimension-one observables are encoded in the gravitational symplectic form on the semi-classical phase-space.

[1] Belin, A., Myers, R. C., Ruan, S. M., Sárosi, G., & Speranza, A. J. (2022). Does Complexity Equal Anything?. Physical Review Letters, 128(8), 081602.

[2] Belin, A., Myers, R. C., Ruan, S. M., Sárosi, G., & Speranza, A. J. (2022). Complexity Equal Anything.

Quantum sensing of nanoscale magnetic phenomena

PLENARY SPEAKERS

Christian Degen

Department of Physics, ETH Zurich, Switzerland

Nanoscale magnetic fields contain rich information about the structure, organization and physics of matter. At a close enough look, almost any material or device generates a magnetic stray field, even if often minute: Examples range from magnetically ordered materials, like ferromagnets and antiferromagnets, to superconducting materials, to currents flowing in conductors, to electronic and nuclear spins in molecules and biological matter. Our group is developing new experimental probes for imaging tiny magnetic fields with nanometer spatial resolution.

In this talk, I will discuss progress with scanning diamond magnetometers in pursuit of this goal. Diamond magnetometers rely on a single spin defect in a probe tip (a nitrogen-vacancy center) and exploit concepts of quantum metrology to reach very high sensitivities. I will discuss instrumental challenges in the fabrication of diamond probes and their integration into scanning probe microscopy (SPM) systems. I will then present some illustrative examples of applications in nanoscale magnetism, such as the imaging of antiferromagnetic domains and domain walls, the flow of current in graphene devices, and magnetic resonance imaging of nuclear spins with atomic spatial resolution.

Spin currents and light-spin interaction in Dirac materials

INVITED SPEAKERS

Masamitsu Hayashi

The University of Tokyo

Generation of spin current is critical to developing technologies based on current-controlled magnetization via spin-orbit torques[1]. Recent studies reveal that, in addition to the 5d transition materials with strong spin-orbit coupling, topological insulators, Weyl semimetals and van der Waal heterostructures may serve as an efficient source of spin current. It is the unique electronic structure of these materials, the large spin Berry curvature in particular, that facilitates generation of spin current. We have studied the spin Hall effect in materials with strong spin orbit coupling, with particular emphasis on semimetals that possess Dirac-like electronic bands[2]. I will cover the origin of the spin Hall effect in Dirac materials, as well as its influence on light-spin interaction[3] in the talk.

[1] Kim et al., Nature Mater. 12, 240 (2013).
[2] Chi et al., Science Advances 6, eaay2324 (2020), Phys. Rev. B 105, 214419 (2022).
[3] Hirose et al. Phys. Rev. B 103, 174437 (2021).

Accurate magnetic field imaging with nanodiamond quantum sensors enhanced by machine learning

CONTRIBUTED SPEAKERS

Kento Sasaki

Department of Physics, The University of Tokyo

Nanodiamonds can be excellent quantum sensors for local magnetic field measurements. In this presentation, we show highly accurate magnetic field imaging by combining nanodiamond ensemble (NDE) and machine learning [1]. We discover the dependence of the NDE signal on the field direction, suggesting the application of NDE for vector magnetometry and the improvement of the existing model. Our method enhances the NDE performance sufficiently to visualize nano-magnetism and mesoscopic current and expands the applicability of NDE in arbitrarily shaped materials, including living organisms. This accomplishment bridges machine learning to quantum sensing for accurate measurements.

[1] M. Tsukamoto et al., Sci. Rep. **12**, 13942 (2022)

PS1-01 Preparation for the Simons Array CMB polarization experiment and development of optical elements

Kana Sakaguri
The University of Tokyo

The cosmic microwave background (CMB) has a variety of information that is useful for understanding the early universe [1, 2]. The Simons Array, an ongoing ground-based CMB experiment, is located in the Atacama plateau in northern Chile, and its second telescope expects the first light soon. For the success of precision measurement of faint CMB signals, the development of optical systems is needed. In particular, anti-reflection (AR) coatings are critical for materials that have high refractive indices. In this poster, I discuss the status of the project and the performance evaluation of AR coatings.

[1] U. Seljak, M. Zaldarriaga, Phys. Rev. D **60**, 043504 (1999)
[2] M. Kamionkowski, A. Kosowsky, A. Stebbins, Phys. Rev. Lett. **78**, 2058 (1997)

PS1-02 The observation of chiral gauge field in the Floquet state of 3D Dirac semimetal $Co_3Sn_2S_2$

Naotaka Yoshikawa
The University of Tokyo

The implement of the chiral gauge field by circularly polarized light irradiation was predicted based on Floquet theory, which leads to the transition from 3D Dirac semimetals into Weyl semimetals, and to exotic electromagnetic responses in the emergent topological phases [1]. We have experimentally demonstrated the light-induced anomalous Hall effect in the paramagnetic phase of $Co_3Sn_2S_2$ by a mid-infrared pump-THz Faraday probe spectroscopy. The pump intensity and driving frequency dependences of the anomalous Hall conductivity are those expected by the Floquet theory, which manifests the implement of chiral gauge field coupled to 3D Dirac electrons [2].

[1] S. Ebihara, K. Fukushima, and T. Oka, Phys. Rev. B **93**, 155107 (2016).
[2] N. Yoshikawa et al., arXiv:2209.11932.

PS1-03 Substrate-induced Broken C_4 Symmetry and Gap Variation in Superconducting Monolayer FeSe/$SrTiO_3$ - /13x/13

Wen Si

Department of Physics, Tokyo Institute of Technology

Monolayer iron selenide (ML FeSe) on strontium titanate ($SrTiO_3$, STO) is a superconductor with T_C over 60 K [1], in which the STO substrate is said to play an essential role in the high- T_C superconductivity. According to our previous research, employing different STO surface superstructures can change the electron doping level and the superconducting gap size of ML FeSe [2]. We performed low-temperature scanning tunneling microscopy/spectroscopy experiments to measure the correlation between the local surface structure and the electronic states and the superconductivity of ML FeSe/ STO - /13x/13. As a result, we observed that topmost Se of ML FeSe arranged in /13x/13 period and the C_4 symmetry of the square /13x/13 unit cell is broken to C_2 symmetry.

[1] Wang Qing-Yan *et al.,* Chinese Phys. Lett. **29**, 037402 (2012)
[2] Tomoaki Tanaka *et al.,* Phys. Rev. B **101**, 205421 (2020)

PS1-04 Unsaturated Large Magnetoresistance in the Quadrupolar Kondo Lattice System $PrTi_2Al_{20}$

Takachika Isomae [1], Akito Sakai [2], Mingxuan Fu [1,2], Takanori Taniguchi [3], Masashi Takigawa [1,4,5], and Satoru Nakatsuji [1,2,6,7,8]

[1] ISSP, [2] Univ. of Tokyo, Dept. of Phys., [3] IMR, Tohoku Univ., [4] KEK-IMSS, [5] Toyota Riken, [6] CREST, [7] JHU, [8] Trans-scale Quantum Science Institute, Univ. of Tokyo,

Quadrupolar Kondo lattice (QKL) system $PrTi_2Al_{20}$ is a suitable system to study exotic transport phenomena induced by multipole moments [1,2]. The transport properties of the QKL system under magnetic fields were investigated by measuring the transverse magnetoresistance and Hall effect in the $PrTi_2Al_{20}$ and non-4f analog $LaTi_2Al_{20}$. At high temperatures, the transport properties of the $PrTi_2Al_{20}$ show different behavior from that of the $LaTi_2Al_{20}$ due to possible quadrupole- induced scattering. On the other hand, at low temperatures, both systems show similar unsaturated large quasi-linear magnetoresistance by the open orbits mechanism.

[1] A. Sakai and S. Nakatsuji, J. Phys. Soc. Jpn. **80**, 063701 (2011).
[2] T. Onimaru and H. Kusunose, J. Phys. Soc. Jpn. **85**, 082002 (2016).

PS1-05

Magnon-polariton in multiferroic $BiFeO_3$

Ryo Kainuma
Department of Physics, Tokyo Institute of Technology

Optical excitation of magnon in antiferromagnets is a challenging building block in opto-magnonics[1]. Especially the non-local propagation characteristics of magnon-polariton have not been elucidated. We experimentally showed that magnon in $BiFeO_3$, a novel multiferroics that exhibits antiferromagnetism and ferroelectricity at room temperature, can couple with terahertz photon generated by Cherenkov-type phase matching[2]. Our time-resolved imaging measurements provided the wave nature of magnon-polariton. We found that the antiferromagnetic magnon propagated over hundreds of micrometers by forming magnon-polariton.

[1] P. Němec *et al., Nat. Phys.* **14**, 229-241 (2018)
[2] D. H. Auston, *Appl. Phys. Lett.* **43**, 713–715 (1983)

PS1-06

Nanodiamond quantum thermometer assisted with machine learning

Kouki Yamamoto
Department of Physics, Graduate School of Science, The University of Tokyo

Nanodiamonds containing nitrogen-vacancy centers can be used for imaging temperature and magnetic field strength [1]. In this study, we have verified a method to determine temperature in a zero magnetic field directly from optically detected magnetic resonance (ODMR) spectra by Gaussian process regression, a type of machine learning. We found that the method using machine learning can read temperature more accurately than conventional methods. In principle, this method should also work for ODMR spectra with complex shapes in a magnetic field [2] and can be developed as a technique to accurately read temperature and magnetic field simultaneously.

[1] C. Foy *et al., ACS Appl. Mater. Interfaces* **12**, 23 (2020).
[2] M. Tsukamoto *et al., Scientific Reports* **12**, 13942 (2022).

PS1-07 NMR study on Bose-Einstein condensation under magnetic fields in quasi-two-dimensional antiferromagnet $YbCl_3$

Eria Imada

Department of Physics, The University of Tokyo

Bose-Einstein condensation (BEC) of hard-core bosons takes place in Heisenberg magnets near the saturation field[1]. The BECs in magnets have been studied mainly on 1D or 3D materials, but quasi-2D materials are attractive since either 2D (the Berezinskii-Kosterlitz-Thouless transition) or 3D characters dominate order and fluctuations[2]. J_{eff} -1/2 Heisenberg antiferromagnet $YbCl_3$ is a suitable platform for a quasi-2D BEC study. Our NMR measurement under a-axis fields actually observes long-range order, 3D BEC. In addition to the observation of the static order, we discuss dimensionalities of dynamic fluctuations in $YbCl_3$.

[1] V. Zapf and M. Jaime, *Reviews of Modern Physics* **86**, 2 (2014)
[2] Y. Matsumoto, et al., arXiv:2207.02329

PS1-08 Direct observation of the superconducting gap in the topological superconductor $PdBi_2$ by low-temperature and high-resolution laser ARPES

Akifumi Mine, Yigui Zhong, Sahand Najafzadeh, Kenjiro Okawa [1], Masato Sakano [2], Kyoko Ishizaka [2], Shik Shin [2], Takao Sasagawa [1], Kozo Okazaki

ISSP, [1] Tokyo Tech, [2] Univ. of Tokyo

$PdBi_2$, of which T_c is ~ 5.8 K and crystal structure belongs to the space group I4/mmm, is known as one of the promising candidates for topological superconductors. According to the first-principles band-structure calculations and synchrotron ARPES, $PdBi_2$ has topologically protected surface states in the vicinity of the Fermi level in terms of the topological quantities [1]. In this study, we have measured the superconducting gaps of $PdBi_2$ by low-temperature and high-resolution laser ARPES. As a result, the existence of the superconducting gaps is confirmed in the target surface bands, and we reveal their details from the analysis including their momentum and band dependence.

[1] M. Sakano, *et al.,* Nat. Commun. **6**, 8595 (2015).

PS1-09 Field-induced re-Insulation in the extreme quantum state of a topological insulator $Bi_{1-x}Sb_x$ (x~0.1)

Yuto Kinoshita
ISSP, The University of Tokyo

The extreme quantum limit state is an ideal playground to explore novel quantum states realized by strong correlation effects. To investigate these states, we focused on a topological insulator $Bi_{1-x}Sb_x$ (x = 0.099). Applying magnetic fields along the trigonal axis, the semiconducting (SC) gap between the conduction and valence bands collapses at a certain field [1]. Further increase in the magnetic field raises the band overlap in the semimetallic (SM) state and an unknown re-insulating state emerged. We discuss the origin from perspective of the excitonic insulator in a magnetic field predicted half a century ago [2].

[1] K. Hiruma and N. Miura, *J. Phys. Soc. Jpn.* **52**, 2118 (1983).
[2] E. W. Fenton, *Phys. Rev.* **170**, 816 (1968).

PS1-10 Cavity magnetomechanics of surface acoustic waves with a synthetic antiferromagnet

Hiroki Matsumoto [1], Daiki Hatanaka [2], Motoki Asano [2], Takuya Kawada [1], Masashi Kawaguchi [1], and Masamitsu Hayashi [1,3]
[1] The Univ. of Tokyo, [2] NTT-BRL, [3] TSQS

Coherent interaction between different physical excitations is essential in developing hybrid quantum systems. Among excitations in solids, magnons in ferromagnets are attractive owing to their frequency tunability and various coupling mechanisms to other excitations [1]. In this work, we develop a surface acoustic waves (SAW) resonator with quality factor of ~10^3 [2] to study the interaction between SAW and magnons in a synthetic antiferromagnet. We show acoustic control of magnons in synthetic antiferromagnets and estimate the coupling strength between the two excitations.

[1] Y. Li *et al., APL Materials* **9**, 060902 (2021).
[2] D. Hatanaka *et al., Phys. Rev. Appl.* **17**, 034024 (2022).

PS1-11 Soft-magnetic skyrmions induced in a sandwich structure with intrinsic ferromagnetic topological insulators

Takuya Takashiro
School of Science, Department of Physics, The University of Tokyo

The introduction of ferromagnetism into topological insulators (TIs) has been actively studied because of interesting phenomena such as the anomalous quantum Hall effect and the magnetic vortices, skyrmions. In this study, we electrically observed skyrmions for the first time in the sandwich structure using an intrinsic ferromagnetic topological insulator (FMTI) $Mn(Bi,Sb)_2Te_4$ and (TI) $(Bi,Sb)_2Te_3$ as $Mn(Bi,Sb)_2Te_4$/ (TI) $(Bi,Sb)_2Te_3$/ $Mn(Bi,Sb)_2Te_4$ [1]. The $Mn(Bi,Sb)_2Te_4$ layer contains a regularly arranged monolayer Mn sheet which induces ferromagnetism. Intriguingly, it is suggested that the surface-state coupling between FMTIs stabilizes skyrmions. In addition, our skyrmions are "soft-magnetic", which is promising for a rewritable skyrmion memory.

[1] T. Takashiro, *et al., Nano Letters* **22**, 881 (2022).

PS1-12 Circularly polarized light-induced terahertz anomalous Hall effect of three-dimensional Dirac electrons in bismuth

Yoshua Hirai
Department of Physics, The University of Tokyo

Floquet engineering has recently attracted the attention of many researchers as a highly controllable method for manipulating/generating material functionalities using light [1]. Though being extensively investigated theoretically, experimental realization of such phenomena is still relatively rare due to technical difficulties such as the problem of heating by light excitation. In an attempt to demonstrate such Floquet-mediated phenomena, we irradiate bismuth, a well-known three-dimensional Dirac electron system [2], with circularly polarized mid-infrared light and probe it with terahertz Faraday rotation. In the poster presentation, we will introduce the experimental results and discuss their relationship with Floquet engineering.

[1] T. Oka and S. Kitamura, *Annu. Rev. Condens. Matter Phys.* **10**, 387-408 (2019)
[2] Y. Fuseya, M. Ogata and H. Fukushima, *J. Phys. Soc. Jpn.* **84**, 012001 (2015)

PS1-13 All-optical switching of chirality and magnetization in ferromagnetic Weyl semimetal $Co_3Sn_2S_2$

Kazuma Ogawa
Department of Physics, The University of Tokyo

Magnetic Weyl semimetals are known to exhibit a gigantic anomalous Hall effect due to the presence of a fictitious gauge field between Weyl points. By irradiation of circularly polarized mid-infrared laser pulses on a thin film of ferromagnetic Weyl semimetal, $Co_3Sn_2S_2$, we achieved optical control of the colossal terahertz anomalous Hall conductivity, originating from the diverging Berry curvature around Weyl nodes. Our results manifest the non-volatile control of chirality of Weyl nodes. Magneto-optical Faraday imaging reveal that this chirality switching can be explained by all-optical switching of magnetization, where the large magnetic circular dichroism of $Co_3Sn_2S_2$ plays a key role.

PS1-14 Cubic ferromagnet and its emergent phenomenon in the vicinity of phase boundary

Seyed Reza Ghazanfari
The University of Tokyo, Institute for Solid State Physics (ISSP)

We studied a 2D ferromagnetic lattice in presence of cubic anisotropy [1] by employing mean field analysis and tensor network calculation. Our 2D infinite projected entangled pair states (iPEPS) [2] results indicate that near the phase boundaries, magnetization undergoes easy axis softening due to an emergent U(1) symmetry. We elaborate the reason from quantum field theory and renormalization group perspective, which suggests the dangerously irrelevant nature of the anisotropy, therefore emergence of continuous symmetry becomes exact right on the critical points where the criticality governs by 3D XY universality class and supported by our iPEPS calculation for correlation function.

[1] J. H. van Vleck, On the Anisotropy of Cubic Ferromagnetic Crystals, Phys. Rev. **52**, 1178 (1937)

[2] J. Jordan, R. Orús, G. Vidal, F. Verstraete and J. I. Cirac, Classical Simulation of Infinite- Size Quantum Lattice Systems in Two Spatial Dimensions, Phys. Rev. Lett. **101**, 250602 (2008)

PS1-15 Magnetic spin Hall effect and its spin-orbit torque in a topological Wely antiferromagnet

Kouta Kondou
RIKEN Center for Emergent Matter Science

Recently we focus on the magnetic spin Hall effect (MSHE) in the topological Weyl antiferromagnet Mn_3Sn, in which the current induced spin-polarization direction systematically changes by manipulating the chiral antiferromagnetic order, i.e., the cluster magnetic octupole [1]. Interestingly, the magnetic order can be controlled by a small external magnetic field[2] or a spin-orbit torque [3, 4]. Here, we will introduce our experimental results on the MSHE and a unique spin-orbit torque due to MSHE in the Mn_3Sn[5].

[1] M. Kimata et al., Nature 565, 627 (2019).
[2] S. Nakatsuji, N. Kiyohara, and T. Higo, Nature 527, 212 (2015)
[3] H. Tsai, T. Higo et al., Nature 580, 608 (2020).
[4] T. Higo, K. Kondou et al., Nature 607, 474-479 (2022)
[5] K. Kondou et al., Nature Communications 12 6491 (2021).

PS1-16 Investigation of magnetic octupole domain wall dynamics in a topological antiferromagnet

Kouta Kondou
RIKEN Center for Emergent Matter Science

Electrical control of the magnetic domain walls is an essential technique for nonvolatile memory devices using magnetic bits. Recently we focus on the magnetic domain wall dynamics in a topological antiferromagnet Mn_3X (X = Sn, Ge). We have reported the possibility of electrically nucleating, displacing, and detecting a magnetic octupole domain wall in a single crystal Mn_3Sn Hall device [1, 2]. Here, we will discuss the recent experimental results on fast domain wall dynamics by using the optical detection technique.

[1] S. Sugimoto, et al. Commun. Phys. 3, 1–9 (2020).
[2] M. Wu, et al. Appl. Phys. Lett. 116, 132408 (2020).

PS1-17 Circular photogalvanic effect in surface superstructures on Si(111) with huge Rashba-splittings

Ibuki Taniuchi, Ryota Akiyama, Rei Hobara, and Shuji Hasegawa

Department of Physics, The University of Tokyo

Circularly polarized light has attracted much attention as a spin injection method because it can excite and drive electrons with spin-selective transitions [1]. In particular, circular photogalvanic effect (CPGE) produces spin-polarized current and it does not require an electrical/magnetic field. Just illumination of circular polarized light can induce a non-reciprocal current if the material has strong enough spin-orbit interaction. We fabricated monolayer samples of (Tl,Pb)/Si(111) which have some surface superstructures with giant Rashba effect [2] in ultrahigh vacuum environment and sequentially measured them electrically in situ with light illumination, resulting in successful observation of CPGE in monolayer materials.

[1] D. Fan et al., Phys. Rev. Res. 2, 023055 (2020).
[2] A. V. Matetskiy et al. Phys. Rev. Lett. 115, 147003 (2015).

PS1-18 Fabrication of sub-micron size MTJ device.

Masahiko Yunokizaki

The University of Tokyo

Magneto tunneling junction (MTJ) devices [1] are attracting attention and being actively researched for next-generation non-volatile memory architecture such as magnetic random access memory. We study the fabrication method and characteristics of MTJ with the device size reduced from photolithography-defined one to 100-nm level.

[1] https://www.nature.com/articles/nmat1257

PS1-19 Extreme nonequilibrium states in strongly-correlated Weyl antiferromagnet studied by terahertz spectroscopy

Takuya Matsuda

The Institute for Solid State Physics, The University of Tokyo

The noncollinear antiferromagnet Mn_3Sn is attracting much attention for application to ultrafast spintronic devices as well as for hosting the correlated magnetic Weyl fermions. We have investigated the intriguing electromagnetic responses by terahertz spectroscopy [1], which can be extended to the study of nonequilibrium dynamics [2]. In this presentation, under extreme nonequilibrium conditions created by high-density photoexcitation, we report on an emergence of less-scattered carriers with an effective mass an order of magnitude smaller than that in equilibrium. The result suggests a drastic change of the band structure by screening the electron correlation.

[1] T. Matsuda et al., Nature Commun. 11, 909 (2020).
[2] T. Matsuda et al., arXiv:2206.06627

PS1-20 Giant and Robust ANE in a Polycrystalline Topological Ferromagnet Fe_3Ga

Zili Feng [1,2,] Susumu Minami [1], Shuhei Akamatsu [1], Akito Sakai [1,2],
Taishi Chen [1,2], Daisuke Nishio-Hamane [2], Satoru Nakatsuji [1,2]

[1] Department of Physics, The University of Tokyo , [2] Institute for Solid State physics, The University of Tokyo

Recent discoveries of the topological magnets have opened a new path for developing a much simpler thermoelectric conversion module using the ANE.[1] To accelerate such innovation, it is essential to design materials suitable for industrial processes, and thus a high ANE material in a polycrystalline form has been highly desired. Here, we report a giant and robust room-temperature ANE in the polycrystalline Fe_xGa_{4-x} (2.96<x<3.15), which can be enhanced up to 5.4 μV/K; this value hits the highest room-temperature record for polycrystalline magnets.[2] Comparison of our experimental results with the theoretical study of the Fe-doping effect on the transport properties of FexGa4-x (2.96<x<3.15) reveals that the Fermi energy tuning near the topological nodal-web structure is the key to enhancing the ANE.

[1] M. Mizuguchi, S. Nakatsuji, Energy-harvesting materials based on the anomalous Nernst effect, *Science and Technology of Advanced Materials,* 2019, 20, 262-275.
[2] Z.L. Feng, S. Minami, S. Akamatsu, A. Sakai, T.S. Chen, D. Nishio-Hamane, S. Nakatsuji, Giant and Robust Anomalous Nernst Effect in a Polycrystalline Topological Ferromagnet at Room Temperature, *Advanced Functional Materials*, 2022, 202206519.

PS1-21

CP^2 Skyrmion crystals in an SU(3) magnet with a generalized Dzyaloshinskii-Moriya interaction

Yuki Amari

The University of Tokyo

I will talk about Skyrmion crystals in the ferromagnetic SU(3) Heisenberg model with a generalization of the Dzyaloshinskii-Moriya interaction [1] and the Zeeman term. Since the order parameter space of the model is the complex projective space CP^2, we call them CP^2 Skyrmion crystals (With this manner, the standard Skyrmion crystals can be termed as CP^1 Skyrmion crystals). The model possesses two different types of CP^2 Skyrmion crystals [2]. We clarify their properties using several physical quantities.

[1] Y. Akagi, Y. Amari, N. Sawado and Y. Shnir, *Phys. Rev. D* **103**, 065008 (2021)

[2] Y. Amari, Y. Akagi, S. B. Gudnason, M. Nitta and Y. Shnir, *Phys. Rev. B* **106**, L100406 (2022)

PS1-22

Development of time-, spin- and angle-resolved photoemission spectroscopy system with 10.7-eV laser at 1-MHz repetition rate

Kaishu Kawaguchi [1], Kenta Kuroda [2], Yuto Fukushima [1], Zhigang Zhao [1], Shuntaro Tani [1], Hiroaki Tanaka [1], Ayumi Harasawa [1], Takushi Imori [1], Ryo Noguchi [1], Koichiro Yaji [3], Shik Shin [4], Fumio Komori [1], Yohei Kobayashi [1], Takeshi Kondo [1]

[1] Institute for Solid State Physics, The University of Tokyo, [2] Graduate School of Advanced Science and Engineering, Hiroshima University, [3] National Institute for Materials Science, [4] Office of University Professor, The University of Tokyo

Spin- and angle-resolved photoemission spectroscopy (SARPES) is a powerful experimental technique to reveal spin-polarized electronic states in energy (E) and momentum (k) space [1]. In addition to this, a SARPES combined with the pump-probe laser technique allows one to visualize the spin texture above the Fermi level. This is also powerful for investigating the photo-induced phase transitions and their spin-evolution or relaxation dynamics in the ultrafast time domain, which provide invaluable insights into the nonequilibrium electronic properties of spin-polarized band structures. The pump-probe SARPES, however, has difficulty in the high-efficiency measurements with high-energy photons. The photoemission spectroscopy, in general, requires high-energy photons to cover a wide k range to observe the entire Brillouin zone. However, probe photons for that purpose are typically generated by the high harmonic generation of a Ti:Sapphire laser with a kHz-class repetition rate. The repetition rate is relatively low for photoemission spectroscopy, causing space charge effects [2] when obtaining photon fluxes large enough to overcome the low spin-detection efficiency in the pump-probe SARPES measurements. As a drawback of this technique, one needs to reduce the photon flux, so that the photoelectron accumulation time becomes unrealistically long. Here, we present our state-of-the-art pump-probe SARPES apparatus overcoming the drawback mentioned above, constructed at ISSP, The University of Tokyo. This apparatus is based on the SARPES system equipped with highly efficient very-low-energy-electron-diffraction (VLEED) spin detectors [3]. We combine this with a bright 10.7-eV pulsed-laser at a high repetition rate (1-MHz), which is driven by the harmonic generation from a Yb:Fiber chirped-pulse amplified laser [4]. It enables us to obtain large SARPES signals enough not only to observe the unoccupied spin-polarized bands in various materials but also to investigate their ultrafast electron and spin dynamics. In particular, the high energy of the probe laser (10.7-eV) allows one to observe the entire Brillouin zone for most of the materials. As an example, we demonstrate the experimental determination of the unoccupied spin-polarized surface states and their ultrafast dynamics in the topological insulator Sb_2Te_3.

[1] T. Okuda and A. Kimura, *J. Phys. Soc. Jpn.* **82**, 021002 (2013)
[2] L.-P. Oloff *et al., J. Appl. Phys.* **119**, 225106 (2016)
[3] K. Yaji *et al., Rev. Sci. Instrum*. **87**, 053111 (2016)
[4] Z. Zhao *et al., Opt. Exp.* **25**, 13517 (2017)

PS1-23 The local conserved quantities of open spin-1/2 XYZ chain

Kouhei Fukai
The University of Tokyo

A macroscopic number of local conserved quantities (LCQ) is a feature of quantum integrable systems and is essentially related to solvability. Although its existence is widely known, the explicit expressions of LCQs are not known in most cases [1]. Our previous study found that of all the LCQs in the closed spin-1/2 XYZ chain [2]. However, in the open boundary case, the structure of LCQs is more complicated because of the absence of the boost operator [3]. We identified the explicit expressions of some new LCQs in the open XYZ chian using the result of [2,3] and found some general properties in their structure.

[1] M P Grabowski and P Mathieu, *Ann. Phys* 243 299 (1995)
[2] Y Nozawa and K Fukai, *Phys. Rev. Lett*. **125** 090602 (2020)
[3] M P Grabowski and P Mathieu, *J. Phys. A: Math. Gen.* **29** 7635 (1996)

PS1-24 Large Hall Signal due to Electrical Switching of an Antiferromagnetic Weyl Semimetal State

H. Tsai [1,2], T. Higo [1,2,4], K. Kondou [2,3], S. Sakamoto [4], A. Kobayash i[4], T. Matsuo [1], S. Miwa[2,4], Y. Otani [2,3,4] & S. Nakatsuji [1, 2, 4]
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The electrical manipulation of a topological state is crucial for utilizing the robust properties of topological materials in electronic devices. Recently, such manipulation is realized in the antiferromagnetic Weyl semimetal Mn_3Sn[1,2] through the readout signal of anomalous Hall effect in the Mn_3Sn/heavy metal (Pt, W) heterostructures[3]. Here, we reported that the switching of Hall signal of Mn_3Sn/heavy metal multilayer can be significantly enhanced by: (i)adjusting the crystal orientation of Mn_3Sn by removing Ru buffer layer, and (ii) changing the interfacial condition by annealing at the interface between Mn_3Sn and the heavy metal. Compared to the reported switching Hall signal in Ru/Mn_3Sn/Pt multilayers, the switching Hall resistance becomes one order larger, ~0.35Ω, in the Mn_3Sn/W devices. The readout voltage can be increased to mV order by increasing the read current. Moreover, by investigating the thickness dependence of Mn_3Sn layer, we found that the effective switching thickness in Mn_3Sn layer could go up to 40nm, which is much thicker than ferromagnetic materials.

[1] S. Nakatsuji, N. Kiyohara, T. Higo, Nature 527, 212-215 (2015).
[2] T. Higo, et al. APL 113, 202402 (2018).
[3] H. Tsai, T. Higo, et al. Nature 580, 608–613 (2020).

PS1-25

Large anomalous Nernst effect in the ferromagnetic Fe_3Si polycrystal

Yangming Wang [1,2], Susumu Minami [1], Akito Sakai [1,2], Taishi Chen [1,2,3], Zili Feng [1,2], Daisuke Nishio- Hamane [2], Satoru Nakatsuji [1,2,4,5,6]

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The high-throughput calculation predicts that the ferromagnet Fe_3Si could exhibit a large anomalous Nernst effect (ANE) owing to the large Berry curvature[1]. Our experimental observation shows the Nernst signal S_{yx} for Fe_3Si polycrystal at room temperature reaches up to 2 μV/K, which is near one order larger than that for pure Fe. The experimental transverse thermoelectric coefficient α_{yx} is also comparable to the theoretical prediction. The high Curie temperature of 840 K and the most abundance of Fe and Si make Fe_3Si a competitive candidate for Nernst-type thermoelectric generations.

[1] Sakai A et al. Nature, 2020, 581(7806): 53-57.

PS1-26

Atomic ordering dependence of anomalous Nernst effect in thin films of the Weyl magnet Co_2MnGa

Ryota Uesugi [1], Tomoya Higo [1-3], and Satoru Nakatsuji [1-5]

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An anomalous Nernst effect (ANE) can be used for thermoelectric generators and as a probe for the topological band structure[1]. ANE is enhanced by Berry curvature and density of states around the Fermi surface. The largest ANE at room temperature was obtained in $L2_1$-ordered Co_2MnGa due to Weyl cones with horizontal band dispersion[2-3]. Since symmetry is a key factor in the topological band structure, understanding the relationship between the symmetry based on the atomic ordering and band structure is required to enhance ANE further. In this presentation, the atomic ordering dependence of ANE in Co_2MnGa films will be discussed.

[1] S. Nakatsuji and R. Arita, *Annual Review of Condensed Matter Physics* **13**, 119 (2022).

[2] A. Sakai, *et.al., Nature Physics* **14**, 1119 (2018).

[3] S. Minami, *et.al., Physical Review B* **102**, 205128 (2020).

PS1-27

Projective spatial symmetry and Lieb-Schultz-Mattis theorem

Yasuhiro Tada

Hiroshima University, The University of Tokyo

Symmetry of a system is fundamental for quantum states. Here, by introducing a tiny U(1) flux , we discuss enhancements of two spatial symmetries, namely (i) translation symmetry [1] and (ii) point group symmetry [2]. The tiny flux has non-perturbative effects on the group structure and the resulting symmetries become projective, while it has only perturbative effects in energy spectra. This enables us to extend the celebrated no-go theorem, Lieb-Schultz-Mattis theorem, which prohibits a unique ground state with an excitation gap.

[1] Y. Tada, *Phys. Rev. Lett.* **127**, 237204 (2021).

[2] Y. Tada and M. Oshikawa, to be submitted.

PS1-28

Testing Electron-phonon Coupling for the Superconductivity in Kagome Metal CsV_3Sb_5

Yigui Zhong [1], S. LiB, H. Liu [3], Y. Dong [1], Y. Arai [1], H. Li [2], Y. Shi [3], Z. Wang [4], S. Shin [1], H. N. Lee [2], H. Miao [1], T. Kondo [1], K. Okazaki [1]

[1] ISSP, The University of Tokyo, [2] Oak Ridge National Laboratory, [3] Institute of Physics, Chinese Academy of Sciences, [4] Boston College

Recently, in a new kagome metal CsV_3Sb_5, superconductivity that intertwines with unconventional charge orders is observed [1, 2]. Density functional theory calculations predicted weak EPC strength [3], λ, supporting an unconventional pairing mechanism. However, experimental determination of λ is still missing, hindering a microscopic understanding of the intertwined ground state. Here, using 7-eV laser-based angle-resolved photoemission spectroscopy and Eliashberg function analysis, we determine an intermediate λ=0.45~0.6 for both Sb *5p* and V *3d* electronic bands, which can support a conventional superconducting transition temperature on the same magnitude of experimental value in CsV_3Sb_5. Our results support an EPC driven superconductivity in CsV_3Sb_5.

[1] B. R. Ortiz *et al., Phys. Rev. Mater.* **3**, 094407 (2019).

[2] C. Mielke, *et al. Nature* **602**, 245-250 (2022).

[3] H. Tan, *et al., Phy. Rev. Lett.* **127**, 046401 (2021).

PS1-29

Topological field theories and gapped Hamiltonians with fusion category symmetries in 1+1 dimensions

Kansei Inamura
Institute for Solid State Physics, The University of Tokyo

We construct all topological quantum field theories (TQFTs) with fusion category symmetries in two spacetime dimensions, including both bosonic and fermionic TQFTs. The construction is accomplished by combining the state sum construction of 2d TQFTs and the pullback of fusion category symmetries. We also write down the corresponding gapped Hamiltonians, which have exact fusion category symmetries on the lattice. As a byproduct of the construction, we derive the bosonization/fermionization formula of fusion category symmetries by comparing the symmetries of bosonic and fermionic TQFTs. This is based on arXiv: 2110.12882 and 2206.13159.

PS1-30

Quantum Monte Carlo Simulation of the Phase Transition and Electric Properties in Kagome Metal

Qifang Li[1,2,3], Gaopei Pan[4], Zi Yang Meng[3], Satoru Nakatsuji[1,5]
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Non-Fermi liquid behaviors have been observed in a wide class of Kagome metals[1]. Quantum Monte Carlo is a powerful tool to simulate the spin degree of freedom and charge degree of freedom at finite temperature[2]. In this poster, I will show the Neel transition of inter-layer antiferromagnetic FeSn, calculated by the stochastic series expansion (SSE) method. Determinant quantum Monte Carlo (DQMC) is also applied to FeSn and a quantitative analysis of the non-Fermi liquid behavior is provided.

[1] Linda Ye, *et al., Nature* **555**, 7698 (2018)
[2] J. E. Hirsch, *Phys. Rev. B* **31**, 4403-19 (1985)

PS1-31

Stochastic approach to cosmic inflation

Yuichiro Tada
Nagoya University

Cosmic inflation, the accelerated expansion phase of the universe in advance of the hot big-bang universe, is now considered as the standard paradigm of the modern cosmology. Not only does it realize a globally homogeneous and isotropic universe, but it can also generate fine density perturbations from the quantum zero-point fluctuation as a source of current cosmic structures like stars or galaxies. In the ordinary approach, the predicted fluctuation in each inflation model is calculated with use of the perturbative quantum field theory (QFT) in the curved spacetime. However, it cannot be applied for large fluctuations which can cause for example the so-called primordial black hole, one candidate of dark matter. Instead of the standard perturbative QFT, the effective theory of the coarse-grained field called stochastic formalism is also known as another powerful tool [1]. In the accelerated expansion spacetime, the coarse-grained effective theory reads a classical (non-quantum), stochastic process (i.e., Brownian motion) and thus even large fluctuations can be treated directly. Since we have developed how to calculate fluctuations in a form conserved even after the end of inflation [2], many aspects of this approach have been investigated. I will introduce these recent developments in the talk.

[1] A. A. Starobinsky, Lect. Notes Phys. **246**, 107-126 (1986)
[2] T. Fujita, M. Kawasaki, Y. Tada and T. Takesako, JCAP **12**, 036 (2013)

PS1-32

Method of images in defect conformal field theories

Yoshitaka Okuyama
Department of Physics, Faculty of Science, The University of Tokyo

Critical phenomena are one of the most appealing subjects in theoretical physics. While they are described by conformal field theory [1], when it comes to realistic setups, we must include the effects of "defects," that is, impurities and the boundaries of the container of the experimental systems. In this presentation based on [2], I describe that the method of images works to calculate correlation functions in defect conformal field theory that describes critical phenomena in the presence of defects.

[1] A. M. Polyakov, JETP Lett. 12 (1970)
[2] T. Nishioka, Y. Okuyama, S. Shimamori, arxiv:2205.05370 [hep-th] (to appear in Physical Review D)

PS1-33 Narain CFTs from quantum error-correcting codes

Kohki Kawabata
The University of Tokyo

Recently, a class of Narain CFTs was constructed from quantum error correcting codes (QECCs) in [1]. We generalize this construction to a larger class of QECCs called qudit codes. In particular, we focus on qudit CSS codes, which are given by a pair of classical linear codes. We also discuss partition functions averaged over qudit CSS codes and their properties.

[1] A. Dymarsky and A. Shapere, JHEP 03 (2021) 160.

PS1-34 Progress towards electron electric dipole moment measurement using laser-cooled francium

Naoya Ozawa
Center for Nuclear Study, The University of Tokyo

The permanent electric dipole moment (EDM) of electrons violates charge conjugation and parity symmetries and serves as a probe for the origin of the matter-antimatter asymmetry in our Universe [1]. Heavy alkali atoms are known to enhance the electron EDM due to relativistic effects, and the enhancement factor is as large as ~800 in case of francium (Fr) [2]. Aiming towards the measurement of the Fr EDM, we are currently developing a beamline to produce and laser-cool Fr atoms, consisting of a surface ionizer [3], an yttrium neutralizer, and a magneto-optical trap. We present the latest status of the experiment.

[1] A. D. Sakharov, *JETP Lett.* **5**, 24 (1967)
[2] N. Shitara *et al., J. High Energ. Phys.* **2021**, 124 (2021)
[3] N. Ozawa *et al., [Manuscript submitted for publication]* (2022)

PS1-35

Error rate of a ferrimagnetic spin shift resister

Mio Ishibashi[1], Kay Yakushiji[2], Masashi Kawaguchi[1], Arata Tsukamoto[3], Satoru Nakatsuji[1, 4-6], Masamitsu Hayashi[1,5]

[1] Univ. of Tokyo, [2] AIST, [3] Nihon Univ., [4] JST-CREST, [5] TSQSI, [6] Johns Hopkins U.

Racetrack memory is a shift register based on current-driven motion of domain walls [1]. Keys to the memory operation are high-speed motion of [2] and low threshold current to move domain walls [3] and the reliability of such processes. Few studies have assessed the reliability of precision positioning of domain walls using current pulses. In this study, we investigate the error rate of a ferrimagnetic shift resister using Kerr microscopy as a magnetic bit detector.

[1] S. S. P. Parkin et al., Science 320, 190 (2008).
[2] L. Caretta et al., Nat. Nanotechnol. 13, 1154 (2018).
[3] H. Awano et al., J. Magn. Magn. Mater. 383, 50 (2015).

PS1-36

Designing an experiment for four-wave mixing with optical nanofiber evanescent dipole-trapped atoms

Zohreh Shahrabifarahani

Okinawa Institute of Science and Technology

The theoretical aspect of the four-wave mixing for a four-level diamond scheme in ^{87}Rb atoms will be discussed. Also, the experimental realization of this study will be presented. In this realization, ^{87}Rb are cooled and further trapped in the vicinity of a nanofiber-based waveguide using a two-color evanescent dipole trap scheme [2]. Then, the four-wave mixing is applied on the trapped atoms in the vicinity of the waveguide giving rise to the better coupling of the generated photon.

[1] PRL 111, 123602 (2013)
[2] Phys. Rev. A 70, 063403 (2004)

PS1-37

Emergent classical gauge symmetry from quantum entanglement

Josh Kirklin
Okinawa Institute of Science and Technology

We describe how entanglement between quantum mechanical subsystems can lead to emergent gauge symmetry in a classical limit. To do so, we explain how the classical consistency of quantum subsystems leads to strong constraints on the entanglement structure of classical states, which we show gives rise to fundamentally non-local classical degrees of freedom. The mechanism we describe is very general, but for concreteness we exhibit some examples, and give evidence that this phenomenon plays a role in the emergence of bulk diffeomorphism invariance in gravity. Based on [1].

[1] Emergent classical gauge symmetry from quantum entanglement, Josh Kirklin, arXiv:2209.03979

PS1-38

Bipartite distributed quantum computing with entanglement-assisting packing processes

Timothy Forrer
The University of Tokyo

Quantum computers have the potential to make a range of classically difficult problems efficiently solvable [1]. However, it is estimated that robust quantum computers powerful enough to solve such problems will take a long time to develop. One way to sooner realise this potential is to distribute the computation across multiple less powerful quantum computers. Here we present a method of distributing quantum computations across two quantum computers using a protocol that consumes one unit of entanglement per use [2], with the aim of reducing the amount of entanglement required by 'packing' multiple uses of this protocol.

[1] A. M. Childs and W. v. Dam, *Rev. Mod. Phys.* 82, 1 (2010)
[2] J. Eisert, K. Jacobs, P. Papadopoulos, and M. B. Plenio. *Phys. Rev. A, 62, 052317* (2000)

PS1-39 Quantum algorithms for transforming Hamiltonian Dynamics

Tatsuki Odake
The University of Tokyo

Quantum computers can simulate the dynamics of wide-ranging quantum systems, yet, the dynamics generated by a complicated Hamiltonian may be hard to implement on a given hardware. In this work, we present a method for efficiently simulating any Hamiltonian that can be obtained from another available Hamiltonian (possibly given as a black box) by a linear transformation. The algorithm relies on performing a series of correlated quantum operations before and after short pulses of the Hamiltonian, using the random compiler QDRIFT [1] as a subroutine. As an example of our technique, we consider estimating the entries of an unknown Hamiltonian.

[1] E. Campbell, *Phys. Rev. Lett.* **123**, 070503 (2019)

PS1-40 Measuring Bell Inequality violation at ATLAS experiment with flavor entanglement of B meson pairs from proton-proton colliders

Tsubasa Ichikawa
QIQB, Osaka University

The Bell inequality is a principal touchstone of testing the local realism posited by Einstein at the time of the formation of quantum theory [1]. The violations of the Bell inequality have been found with the measured system of photons, electrons or nucleons at low energies, which reject local realism. Extending to systems with higher energies will be important for establishing the nonlocal nature universally. Our simulation study demonstrated the feasibility of the Bell test by means of flavor entanglement of a pair of B mesons in the ATLAS experiment at CERN [2]. This will be the first case of violation of the Bell inequality in the community of particle physics experiment, given that the earlier attempt with the Belle experiment was found to be inconclusive, due primarily to the lack of selection process of spacelike events and that of the independent identification of the decay times [3]. This talk will present the method of the Bell test and the expected sensitivity at the ATLAS experiment as well as the status on preparation for the measurement at ATLAS Run 3 starting in 2022.

[1] A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47**, 777 (1935)
[2] Y. Takubo, T. Ichikawa, S. Higashino, Y. Mori, K. Nagano, and I. Tsutsui, Phys. Rev. D **104**, 056004 (2021)
[3] T. Ichikawa, S. Tamura, and I. Tsutsui, Phys. Lett. A **373**, 39 (2008)

PS1-41 Quantum networks with coherent routing of information through multiple nodes

Hlér Kristjánsson
The University of Tokyo

Large-scale communication networks, such as the internet, achieve the transmission of information from a sender to a distant receiver by routing packets of data through many intermediate nodes. Classically, each packet has to follow a well-defined path through the network. In a quantum network, however, it is in principle possible to route information along multiple paths in a coherent quantum superposition. Here we develop a model of quantum communication network with coherent routing of information through multiple intermediate nodes. In this model, we show that the distance over which information can be transmitted reliably can be significantly extended. Based on [1].

[1] Hlér Kristjánsson, Y. Zhong, A. Munson, G. Chiribella, arXiv preprint arXiv:2208.00480 (2022)

PS1-42 Quantum simulation of Dirac, Majorana, and Weyl fermions in first quantization

Shigetora Miyashita
Faculty of Environment and Information Studies, Keio University

To perform accurate calculations of heavy atoms and relativistic phenomena, it is necessary to solve relativistic wave equations [1]. However, prior work has shown that four-component calculations incur significant iteration costs [2]. Here, we develop the first-quantized quantum algorithm for time-dependent relativistic Hamiltonians and perform a detailed analysis of the finite resources required for its optimal implementation. It is found that with an increase in spinor components, the number of iterations of this method remains constant unlike that in the case of classical methods. Furthermore, two-qubit gates scale better for a free particle in comparison with a discrete-time quantum walk.

[1] J. W. Braun, Q. Su, and R. Grobe, *Phys. Rev.* **A 59**, 604 (1999)
[2] S. Sun, et al., *J. Chem. Theory Comput.* **17**, 6 (2021)

PS1-43

Comparison of unknown unitary channels with multiple uses

Yutaka Hashimoto
The University of Tokyo

Comparison of quantum objects is a task to determine whether two unknown quantum objects are the same or different. The optimal strategy of pure-state comparison is known [1], but the optimal strategy of unitary comparison was not known. We obtain the optimal minimum-error and the optimal unambiguous strategies of unitary comparison of two unknown unitary channels based on the quantum tester formalism. It highlights the difference between corresponding tasks for states and channels, which has been previously shown for quantum discrimination tasks [2].

[1] M. Sedl´ak, M. Ziman, V. Buˇzek, and M. Hillery, Unambiguous comparison of ensembles of quantum states, Phys. Rev. A 77, 042304 (2008).

[2] A. Ac´ın, Statistical Distinguishability between Unitary Operations, Phys. Rev. Lett. 87, 177901 (2001).

DAY 2

WEDNESDAY,
NOVEMBER 9, 2022

SESSION 3

QUANTUM INFORMATION

Chair: P.Höhn (OIST)

SESSION 4

HIGH-T_c AND BEYOND

Chair: S. Nakatsuji (U. Tokyo)

Quantum Unclonability and Cryptography

PLENARY SPEAKERS

Anne Broadbent

Department of Mathematics and Statistics, University of Ottawa

According to the no-cloning principle of quantum information, it is not possible, in general, to duplicate an unknown quantum state. In this talk, we will discuss how his unclonability property permeates quantum cryptography.

We start with the early finding of Wiesner on unforgeable quantum money, that established a technique called conjugate coding, which encoding information in random, nonorthogonal bases. This technique is, today, at the foundation of much of quantum cryptography and it plays a key role in the groundbreaking work of Bennett and Brassard on quantum key distribution.

We next discuss recent work that shows how conjugate coding enables certified deletion: a way to unconditionally certify that encrypted information has been erased, meaning that an adversary cannot read the original information, even if the entire decryption key is revealed. This feat is clearly impossible with classical encodings alone.

Finally, we will review unclonable encryption, which, once more, is a situation where we use conjugate coding and, via a monogamy-of-entanglement relation are able to show that the quantum encryption scheme allows to unconditionally prevent an adversary from duplicating the underlying plaintext, meaning that it is impossible for two malicious recipients to decrypt, even if the key is completely leaked.

Universally superposing quantum operations toward quantum functional programming

INVITED SPEAKERS

Mio Murao

Department of Physics, The University of Tokyo

Unitary operations are a fundamental components of quantum algorithms, but they seem to be far more useful if given with a "quantum control" as a controlled unitary operation, a coherent superposition of two different unitary operations depending on a control qubit. Quantum algorithms can be represented by quantum operations beyond unitary operations. Nevertheless, it is not a priori clear if a controlled form of these general quantum operations can be well-defined. To provide a novel tool in the toolbox for quantum programming, we propose a mathematically consistent definition of a controlled form of deterministic but non-unitary quantum operations and, more generally, quantum supermaps (quantum combs), higher-order transformations for quantum operations. We propose a higher-order transformations called "neutralization", which generates the identity operation to a particular set of input quantum operations, and study its controlled form based on our definition. We show that implementations of the controlled neutralization comb lead new universal controllization algorithms for divisible unitary operations.

Reference: Q. Dong, S. Nakayama, A. Soeda, and M. Murao, arXiv:1911.01645

Universal trade-off structure between symmetry, irreversibility, and quantum coherence in quantum processes

CONTRIBUTED SPEAKERS

Hiroyasu Tajima

The university of electro-communications

We find a universal trade-off relation for the irreversibility of dynamics on a local system caused by global dynamics with symmetry [1,2]. This result follows only from the unitarity and global symmetry of the total dynamics and restricts many types of irreversibility, including thermodynamic irreversibility. Therefore, this result has many applications. Applying the trade-off to the Hayden-Preskill black hole model [3], we rigorously show that the rate of information escape from a black hole varies significantly with and without energy conservation. Our trade-off also unifies various restrictions on measurements, quantum computation gates, and quantum error corrections imposed by symmetry.

[1] H. Tajima and K. Saito, arXiv:2103.01876 (2021).
[2] H. Tajima, R. Takagi and Y. Kuramochi, arXiv:2206.11086 (2022).
[3] P. Hayden and J. Preskill, JHEP 0709:120,2007 (2007)

The Planckian Limit in Strange Metals

PLENARY SPEAKERS

Brad Ramshaw

Cornell University

Strange metals have strange resistivity: linear-in-temperature (T-linear) down to low temperature. Strange metals are found in many families of correlated electron materials, leading to the conjecture that a universal bound - the "Planckian" bound - limits the scattering rate of electrons to a value set only by fundamental constants of nature [1]. If the Planckian bound exists, it would provide a natural explanation for why a host of seemingly disparate systems, including high-temperature superconductors and twisted bilayer graphene, all have T-linear resistivity in their phase diagrams. Perhaps most dramatically, T-linear resistivity suggests that electron-electron interactions are so strong that conventional concepts such as quasiparticles and Boltzmann transport do not apply in strange metals [2].

We have measured the angle-dependent magnetoresistance (ADMR) of Nd-LSCO: a strange metal with perfectly T-linear resistivity down to the lowest measured temperatures. We find two remarkable results: 1) we can model our entire data set using Boltzmann transport and a conventional Fermi surface [3]; and 2) we extract a transport scattering rate that saturates the Planckian bound [4]. We show that our extracted Fermi surface and scattering rate are quantitatively consistent with other transport properties including the Hall effect, both the in-and-out-of-plane resistivity, and the high-field magnetoresistance. These results suggest that quasiparticles are alive and well in this strange metal, despite T-linear resistivity and a scattering rate that saturates the Planckian bound. We report new measurements of the thermal and electrical Hall effects in strange metals that disentangle the contributions of elastic and inelastic scatterers, potentially pointing to a resolution of the apparent contraction of Planckian scattering in a metal where Boltzmann transport works.

[1] J.A.N. Bruin et al., Similarity of scattering rates in metals showing T-linear resistivity. Science 339, 804–807 (2013).

[2] S.A. Hartnoll, Theory of universal incoherent metallic transport. Nature Physics 11, 54-61 (2015).

[3] Y. Fang et al., Fermi surface transformation at the pseudogap critical point of a cuprate superconductor. Nature Physics 18, 558-564 (2022).

[4] G. Grissonnanche et al., Linear-in temperature resistivity from an isotropic Planckian scattering rate. Nature 595, 667-672 (2021).

Unveiling doped Mott states of high-T_c cuprate superconductors

INVITED SPEAKERS

Takeshi Kondo

The Institute for Solid State Physics, The University of Tokyo,
Trans-scale Quantum Science Institute, The University of Tokyo

The superconductivity with a high critical temperature (T_c) is generated by carrier doping to a Mott insulator in cuprates. Therefore, the understanding of the electronic properties of CuO_2 planes with a low carrier concentration close to the half-filed Mott state is essential to elucidate the mechanism of the high-T_c superconductivity. The doped Mott state characterized by the strong correlation leads to various exotic states, such as antiferromagnetic state, pseudogap state, preformed pair state, nematic charge density wave, and pair density wave. Theoretically, it has been long predicted that the doped Mott state forms a small Fermi pocket in the electronic structure, which, however, had not been observed despite a tremendous research effort. Recently, we have successfully observed this symbolic feature of cuprates by angle-resolved photoemission spectroscopy and quantum oscillation measurements [1]. I will talk about the key which led us to this observation, and also introduce an idea of origin for the mysterious object, famous as the "Fermi arc", which cannot be understood by textbook physics.

[1] S. Kunisada et al., Science **369**, 833–838 (2020).

Theoretical Exploration of Hydride Superconductors

INVITED SPEAKERS

Shinji Tsuneyuki

Department of Physics, The University of Tokyo

Recently, the search for high-temperature hydride superconductors has become more active with the discovery of sulfur hydrides with superconducting transition temperatures exceeding 200 K under ultrahigh pressure [1]. The background of this research is the predictions of Wigner and Huntington that molecular hydrogen will dissociate and become metallic under ultrahigh pressure [2] and Ashcroft that the metallic hydrogen should exhibit high-temperature superconductivity [3]. In recent years, the methods to search for crystal structures and to quantitatively predict the superconducting transition temperature using first-principles electronic structure calculations have also played a significant role. I will overview these theoretical studies and give their prospects.

[1] A. P. Drozdov et al.,　Nature 525, 73 (2015).
[2] E. Wigner and H.B. Huntington, J. Chem. Phys. 3, 764 (1935).
[3] N. Ashcroft, Phys. Rev. Lett. 21, 1748 (1968).

Strange universe in correlated quantum matter driven by entanglement between multipoles and conduction electrons

CONTRIBUTED SPEAKERS

Mingxuan Fu

Department of Physics, The University of Tokyo

Quantum criticality (QC) and strange metals are overarching topics that connect the historically disparate fields, ranging from condensed matter and quantum optics to general relativity and high energy physics. Though there is increasing recognition that electron orbitals are essential ingredients for realizing exotic emergent phenomena in strongly correlated matters [1], novel QC and strange metals originating from orbital effects remain scarce. Here, we focus on the magnetic field-tuning quantum criticality in a model multipolar Kondo material PrV_2Al_{20}, whose low-energy physics is dominated by Kondo entanglement between local multipoles (i.e., orbitals) and conduction electrons [2]. Using transport and thermodynamic probes at ultralow temperatures and high fields, we show that the evolution of strange metal phases and Fermi surface across the multipolar quantum critical regime drastically differs from that in the familiar magnetic setting.

[1] S. Paschen & Q. Si, Nat. Rev. Phys. 3, 9-26 (2021)
[2] A. Sakai and S. Nakatsuji, J. Phys. Soc. Jpn. **80**, 063701 (2011)

DAY 3

THURSDAY,
NOVEMBER 10,2022

SESSION 5

ASTROPHYSICS AND COSMOLOGY

Chair: K. Fukushima (U. Tokyo)

SESSION 6

TOPOLOGICAL PHENOMENA

Chair: M. Oshikawa (U. Tokyo)

Poster Session 2

Chair: M. Hayashi (U. Tokyo)

Extreme quantum matter in neutron stars and its implications for multi-messenger astrophysics

PLENARY SPEAKERS

Sanjay K. Reddy

Institute for Nuclear Theory, University of Washington

Neutron stars are poised to play a leading role in this multi-messenger era of astrophysics. Recent astronomical observations and theoretical advances have begun to provide new insights into the nature of quantum matter at extreme density. The properties of matter at supranuclear density shape the gravitational wave, neutrino, and electromagnetic emission from extreme phenomena such as the coalescence of binary neutron stars, neutron star-black hole mergers, and core-collapse supernovae. I will highlight what we know and outline the prospects for breakthrough discoveries in the coming decades. I will also discuss how neutron stars can help constrain or discover the particle nature of dark matter.

Chemical View of Star and Planet Formation

INVITED SPEAKERS

Satoshi Yamamoto

Department of Physics and RESCUE, The University of Tokyo

In the formation of sun-like protostars, a disk structure forms around a newly formed protostar and evolves to a protoplanetary disk and eventually to a planetary system. Along this physical process, chemical composition of the interstellar gas also evolves into that of planetary materials. Toward thorough understandings of the origin of the Solar System, we are elucidating these physical and chemical processes with the state-of-the-art radio telescopes including Atacama Large Millimeter/ submillimeter Array (ALMA). Some highlights are summarized as follows:

(1) Chemical composition in Solar-type protostellar cores is much more complex than ever thought. Fairly complex organic molecules have already been formed there. Interestingly, the chemical composition is found to be different from object to object [1,2]. This chemical diversity will be inherited eventually to planetary systems [3-5].

(2) On the other hand, a basic physical structure of disk forming regions consists of an infalling-rotating envelope, a rotating disk structure, and a transition zone between them, regardless of chemical characteristics.

(3) Chemical composition drastically changes in the transition zone. Some specific molecules are found to trace specific physical parts just like ‘a molecular marker’. Thus, we can disentangle complex physical structures of disk forming regions by using molecular distributions [3-7].

These findings will contribute to understandings of our material origin in the Universe in conjunction with those derived from various space missions to the Solar system bodies.

[1] N. Sakai, N. and S. Yamamoto, Chemical Review 113, 8981 (2013).
[2] A.E. Higuchi et al. Astrophysical Journal Supplement Series, 236, 52 (2018).
[3] N. Sakai et al., Nature, 507, 78 (2014).
[4] Y. Oya et al., Astrophysical Journal, 824, 88 (2016).
[5] Y. Okoda et al., Astrophysical Journal, 935, 136 (2022).
[6] Y. Oya and S. Yamamoto, Astrophysical Journal, 904, 185 (2020)
[7] M. Imai et al. Astrophysical Journal, 934, 70 (2022)

Exploration of Inflation and Dark Universe through Cosmic Microwave Background

INVITED SPEAKERS

Akito Kusaka

The University of Tokyo / Lawrence Berkeley National Laboratory

In the coming decade, we foresee a rich and fruitful evolution in the field of cosmic microwave background (CMB) observations. Polarization measurements at degree angular scales constrain possible primordial gravitational waves, probing inflation and quantum fluctuations of gravity. Polarization fluctuations at arcmin angular scales, on the other hand, trace the growth of large-scale structure via gravitational lensing effects. These data sets are rich for measuring dark energy, the neutrino mass, and the evolution of galaxies and clusters. There also are emerging possibility of observing variability of microwave sky to constrain cosmic Axions. In this talk, I will review these CMB science and some of the recent results from CMB observations.

Waves of Topological Origin in the Fluid Earth System

PLENARY SPEAKERS

Brad Marston

Brown University

Symmetries and topology play central roles in our understanding of physical systems. Topology, for instance, explains the precise quantization of the Hall effect and the protection of surface states in topological insulators against scattering from disorder or bumps. However discrete symmetries and topology have not, until recently, contributed much to our understanding of the fluid dynamics of oceans and atmospheres. In this talk I show that, as a consequence of the rotation of the Earth that breaks time reversal symmetry, equatorially trapped Kelvin and Yanai waves emerge as topologically protected edge modes. The non-trivial structure of the bulk Poincare´ waves revealed through the first Chern number guarantees the existence of these waves. Thus the oceans and atmosphere of Earth naturally share basic physics with topological insulators [1]. As equatorially trapped Kelvin waves in the Pacific ocean are an important component of El Niño Southern Oscillation, we have demonstrated that topology plays a surprising role in Earth's climate system. I discuss our recent direct detection of topological signatures of gravity waves in observations of Earth's stratosphere. We have also predicted that waves of topological origin will arise in magnetized plasmas [2]. An experiment at UCLA's Basic Plasma Science Facility will look for the waves.

[1] Delplace, P., Marston, J. B. & Venaille, A. Topological origin of equatorial waves. *Science* **358**, 1075–1077 (2017).

[2] Parker, J. B., Marston, J. B., Tobias, S. M. & Zhu, Z. Topological Gaseous Plasmon Polariton in Realistic Plasma. *Physical Review Letters* **124**, 195001 (2020)

Detection and manipulation of topological responses in the Weyl antiferromagnet Mn_3Sn

CONTRIBUTED SPEAKERS

Tomoya Higo [1-4], Kouta Kondou [3-5], Takuya Nomoto [6,7], Masanobu Shiga [2], Shoya Sakamoto [2], Xianzhe Chen [2], Ryota Uesugi [2], Daisuke Nishio-Hamane [2], Ryotaro Arita [3-6], Yoshichika Otani [2-5,8], Shinji Miwa [2-4,8], and Satoru Nakatsuji [1-4,8,9]

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The Weyl antiferromagnet Mn_3Sn, which exhibits large spontaneous responses owing to Berry curvature associated with the topological band structure, is a promising material not only for research on topological quantum phenomena but also for applications such as ultrafast information carriers [1]. Successful fabrication of Mn_3Sn thin films enables studying its functional properties for electronic devices, e.g., electrical detection and manipulation of the large topological responses [2]. In this presentation, our recent research progress on the thin film and interface properties of Mn_3Sn will be reported [3].

[1] S. Nakatsuji and R. Arita, *Annu. Rev. Condens. Matter* **13**, 119 (2022).
[2] H. Tsai, T. Higo et al., *Nature* **580**, *608 (2020).*
[3] T.Higo, K. Kondou et al., *Nature* **607**, 474 (2022); *Adv. Funct. Mater.* **31**, 2008971 (2021).

Metrology of Band Topology via Resonant Inelastic x-ray Scattering [1]

CONTRIBUTED SPEAKERS

Sangjin Lee

Institute of Basic Science – Center for Artificial Low Dimensional Electronic Systems

Topology is a central notion in the classification of band insulators. However, being inherently a global property depending on the entirety of the system, its direct measurement has remained elusive to local experimental probes in many cases. In this talk, we demonstrate various topological band indices can be directly probed by inelastic x-ray scattering and show crystalline symmetry eigenvalues at the TRIM points leads to distinct scattering intensity. We also demonstrate our protocol in several examples from 1D SSH chain to 3D topological insulator and chiral hinge insulator. Our result establishes an bulk probe for the measurement of band topology.

[1] Sangjin Lee, K.H. Jin, B. Kang, B. J. Kim and G.Y. Cho, arXiv:2108.02211

PS2-01 Torsion-Bar Antenna for Low-Frequency Gravity Gradient Observation

Yuka Oshima
The University of Tokyo

Torsion-Bar Antenna (TOBA) is a low-frequency gravity gradient detector using torsion pendulums [1]. Gravity gradient is measured as differential rotation of two horizontally suspended bars. The resonant frequency of torsional motion is ˜1 mHz, therefore TOBA has good design sensitivity between 0.1 Hz – 10 Hz. TOBA can be used for earthquake early warning and gravitational-wave observation. A 35 cm-scale torsion pendulum and readout optics are under development. In this symposium, we will show the principle and experimental status of TOBA

[1] M. Ando et al., Phys. Rev. Lett. 105, 161101 (2010)

PS2-02 Sublattice selectivity of the inverse Faraday effect in ferrimagnets

Toshiki Hiraoka
Department of Physics, Tokyo Institute of Technology

When the circularly polarized light incidents magnetic materials, the magnetic field is induced in the materials. This phenomenon is called the inverse Faraday effect. Magnetization dynamics can be induced by light through the effect without thermal effect [1] [2]. The inverse Faraday effect field induced in ferromagnets can be easily assumed. However, in ferrimagnets, the field is unclear because these materials have two magnetic sublattices arranged opposite. We revealed that the magnetic sublattices in ferrimagnets affect selectively the inverse Faraday effect by measuring the magnetization dynamics in a rare earth iron garnet induced by the inverse Faraday effect.

[1] A. H. M. Reid, A. V. Kimel, A. Kirilyuk, J. F. Gregg, and Th. Rasing, *Phys. Rev. Lett.,* **105**, 107402 (2010)
[2] A. Stupakiewicz and T. Satoh, *J. Phys. Soc. Jpn.,* **90**, 081008 (2021)

PS2-03 Heavy fermion multigap superconductivity in the ferroquadrupole ordered state of $PrTi_2Al_{20}$

A. Sakai, Y. Matsumoto, M. Fu, M. Tsujimoto, E. O'Farrell and S. Nakatsuji

Department of Physics, The University of Tokyo

A cubic Pr-based rare-earth compound $PrTi_2Al_{20}$ possesses a unique crystalline electric field ground state called cubic nonmagnetic Γ_3, where only quadrupolar and octupolar degrees of freedom are active. Besides, $PrTi_2Al_{20}$ exhibits a ferroquadrupolar (FQ) order at T_Q ~ 2.0 K, followed by a superconducting (SC) transition at T_c ~ 0.2 K. In this presentation, we will present our recent study for the SC and normal state properties of $PrTi_2Al_{20}$ and $Pr_{1-x}La_xTi_2Al_{20}$ via thermodynamic and transport probes. The Two-gap behavior of SC found in undoped $PrTi_2Al_{20}$ vanishes rapidly with a small amount of La doping, indicating the unconventional nature of the SC.

[1] A. Sakai and S. Nakatsuji, J. Phys. Soc. Jpn., 80, 063701 (2011).

[2] A. Sakai, K. Kuga, and S. Nakatsuji, J. Phys. Soc. Jpn., 81, 083702 (2012).

[3] M. Tsujimoto et al., Phys. Rev. Lett. 113, 267001 (2014).

PS2-04 Detail investigation on the relation between the magneto-transport properties and the chiral anomaly in the Weyl antiferromagnet Mn_3Sn

Shunichiro Kurosawa [1], Mingxuan Fu [1], Akito Sakai [1], Muhammad Ikhlas [2] and Satoru Nakatsuji [1,2,3]

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Chiral anomaly is one of the specific features in the Weyl semimetals [1]. This induces the negative longitudinal magnetoresistance, which is frequently used as the proof of the Weyl fermions. However, this anisotropic magneto-transport is affected by mainly the magnetic anisotropy, which makes it difficult to prove the chiral anomaly especially in the Weyl magnet.

To investigate the interplay between the chiral anomaly and the magnetization, we present the magneto-transport properties of Weyl antiferromagnet $Mn_{3+x}Sn_{1-x}$ [2], with three different Mn doping levels. Our experiments show the robustness of the chiral anomaly against the spin fluctuation and the strong correlation [3].

[1] H. B. Nielsen and M. Ninomiya, Physics Letters B 130, 389 (1983).

[2] K. Kuroda et al., Nat. Mater. 16, 1090 (2017).

[3] S. Kurosawa et al., arXiv:2204.00882 (2022)

PS2-05

Preferred orientation and improved interfaces in sputtered Mn_3Sn/Ta films

Takumi Matsuo
Dept. of Physics, The University of Tokyo

The chiral antiferromagnet Mn_3Sn exhibits macroscopic responses due to its time reversal symmetry breaking magnetic structure [1]. Its spins can be manipulated by spin-orbit torque from a neighboring heavy metal (HM), indicating its promise to be used in antiferromagnetic memory devices [2]. Annealing the HM and Mn_3Sn layers together yields a flat film surface; however, the HM and Mn_3Sn tend to react and produce impurities [3]. We demonstrate that a smooth interface without impurities can be realized when HM=Ta. The Mn_3Sn films also have a preferred crystal orientation as opposed to being a random polycrystal, which enhances its magnetotransport properties.

[1] S. Nakatsuji *et al., Nature.* **527**, 212-215 (2015)
[2] H. Tsai, T. Higo *et al., Nature* **580**, 608-613 (2020)
[3] H. Tsai *et al., Small Sci.* **202000025** (2021)

PS2-06

Electronic topological transition of 2D boron by the ion exchange reaction

Zhang Xiaoni

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Researches on Dirac Fermions in two-dimensional (2D) atomic layers, such as graphene, have attracted extensive sinterests. Design and synthesis of 2D Dirac materials have been one of the challenging issues in the field of both chemistry and physics. Boron, as the next element of carbon in periodic table, has potential to be next platform to achieve 2D Dirac materials. Boron-based materials including borophene and hydrogenated borophene (borophane, hydrogen boride) [2] were predicted to show topological properties.

Recently, a monatomic network of hydrogen boride (HB) with the five- and seven-membered rings (5,7-rings) was designed based on the non-symmorphic symmetry group *Pbam*, that has been paid attentions due to generations of the Dirac nodal loops or lines (DNLs). Electronic structure of the 5,7-rings borophane was predicted to be Dirac Nodal semimetal by the topological classification based on the Z_2 invariant [3].

In this report, we synthesized the 5,7-rings hydrogen boride layers from metallic boride $YCrB_4$, by ion-exchange method. The change of chemical states was examined by X-Ray photoelectron Spectroscopy and Infrared Ray Spectroscopy. Together with DFT calculation, the 5,7-rings hydrogen boride was found to be semimetal with DNL, while starting material $YCrB_4$ was semiconductor. An unveiled topological electronic transition was developed and investigated systemically with the non-symmorphic 2D boron under the different chemical environments.

[1] I. Tateishi, **X. Zhang**, IM *et al.,* Molecules 27.6, 1808 (2022).

[2] N. T. Cuong *et al.,* Phys. Rev. B **101**, 195412 (2020).

[3] **X. Zhang**, IM *et al.,* J. Phys. Chem. C 126, 30, 12802–12808 (2022)

PS2-07 The Chirality-dependent second-order spin current in systems with time-reversal symmetry

Ryosuke Hirakida
The University of Tokyo

The spin polarization phenomenon called chirality-induced spin selectivity (CISS) has recently attracted much attention [1]. While the theory of CISS in organic materials has been intensively investigated, that in inorganic materials has not been explored [2]. It is known that spin currents linear in the electric field do not arise in single-channel systems with time-reversal symmetry [3]. This fact makes the construction of the CISS theory difficult.
We constructed a chiral tight-binding model with time-reversal symmetry and evaluated spin currents. It was clarified that spin currents vanish in the linear regime, while second-order spin currents can be finite.

[1] R. Naaman et al., *Annu. Rev. Phys. Chem.* **66**, 263–81 (2015).
[2] F. Evers et al., *Adv. Mater.* **34**, 2106629 (2022).
[3] J. H. Bardarson, *J. Phys. A: Math. Theor.* **41**, 405203 (2008).

PS2-08 Growth of atomically flat topological crystalline insulator SnTe(001) thin films using the room temperature wetting layer method and its electrical transport measurements

Ryota Akiyama
The University of Tokyo

Topological crystal insulators (TCIs) whose surface states are protected by crystal mirror symmetry have attracted much attention because of their exotic properties [1]. (Pb,Sn)Te is one of the typical TCIs. However, it has been very difficult to grow thin and flat films on an insulating substrate. In this study, we succeeded in fabricating atomically flat SnTe ultra-thin films on an insulating SrTiO3(001) (STO) substrate, and evaluated its structure and electrical conduction. As a result, 2-dimensional weak antilocalization has been observed, suggesting that the film thickness is reduced to observe the interference between the top and bottom surface states.

[1] R. Akiyama et al., Nano Research 9, 490 (2016).

PS2-09

Giant orbital polarization at the Fe/MgO interface probed by depth-resolved x-ray magnetic circular dichroism

Shoya Sakamoto [1], Masahito Tsujikawa [2], Masafumi Shirai [2], Kenta Amemiya [3], and Shinji Miwa [1,4]

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The Fe/MgO interface is essential in spintronics because it shows strong interfacial perpendicular magnetic anisotropy and giant tunneling magnetoresistance. To enhance these effects, it is vital to characterize the interfacial spin and orbital magnetic moments. For such a purpose, we performed depth-resolved x-ray magnetic circular dichroism (XMCD) measurements [1]. We find that the spin and orbital magnetic moments are enhanced at the interface. The orbital enhancement is much more significant than that predicted by the standard density functional theory. We attributed this giant enhancement to the electron–electron correlation resulting from electron localization at the interface.

[1] Shoya Sakamoto *et al.,* ACS Appl. Electron. Mater. **4**, 1794–1799 (2022)

PS2-10

Breaking down the magnonic Wiedemann-Franz law in the hydrodynamic regime

Ryotaro Sano

Department of Physics, Kyoto University

Recent experiments have shown an indication of a hydrodynamic magnon behavior in ultrapure ferromagnetic insulators [1]; however, its direct observation is still lacking. Here, we derive a set of coupled hydrodynamic equations and study the thermal and spin conductivities for such a magnon fluid [2]. We reveal the drastic breakdown of the magnonic Wiedemann-Franz law as a hallmark of the hydrodynamic regime, which will become key evidence for the experimental realization of an emergent hydrodynamic magnon behavior. Therefore, our results pave the way towards the direct observation of magnon fluids and their applications to innovative functionalities in magnetically ordered systems.

[1] C. Du, *et al.*, Science **357**, 195 (2017)
[2] **R. Sano** & M. Matsuo, arXiv:2208.14458 (2022)

PS2-11

Anomalous Nernst effect in the iron-based kagome ferromagnet Fe_3Sn

Susumu Minami [1], Akito Sakai [1], Taishi Chen [2], Yangming Wang [1], Zili Feng [3], Takuya Nomoto [4], Motoaki Hirayama [4], Rieko Ishii [3], Takashi Koretsune [5], Ryotaro Arita [4,6], Satoru Nakatsuji [1,3]

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The anomalous Nernst effect (ANE) has recently attracted much attention in terms of thermoelectric device applications[1]. In this study, we focused on Fe-based materials and searched for materials that exhibit giant ANEs. We found the kagome ferromagnet Fe_3Sn, and its ANE signal exceeded three microvolts per kelvin. We also clarified that the two-dimensional structure of the electronic state composed of up and down spins induces the giant Berry curvature, which is the origin of the experimentally observed ANE [2].

[1] S. Nakatsuji and R. Arita, Annu. Rev. Cond. Matter Phys. **13**, 119 (2022).
[2] T. Chen et al., Sci. Adv., 8(2) eabk1480 (2022).

PS2-12

Unusual Superconductivity in the Nodal-Line Semimetal NaAlSi

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NaAlSi is a superconductor with T_c ~ 7 K [1]. Recently, it was reported that the superconducting transition in resistivity under magnetic fields exhibits a two-step transition, which may originate from fractional superconductivity [2]. To understand the origin of the fractional superconductivity, we have determined the magnetic field angle dependence of the resistive transitions. We show that the fractional superconductivity has a two-dimensional character and suggest that it occurs at the crystal surface. It would be interesting if the fractional superconductivity is related to the topological surface state which is indicated by band calculations [3].

[1] T. Yamada et al., J. Phys. Soc. Jpn. 90, 034710 (2021)
[2] D. Hirai et al., J. Phys. Soc. Jpn, 91, 024702 (2022)
[3] X. Yi et al., J. Mater. Chem. C 7, 15375 (2019)

PS2-13 Large magneto-optical Kerr effect in polycrystalline Mn_3Sn thin films

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Non-collinear antiferromagnet Mn_3Sn is an excellent candidate for spintronics device with its novel responses, such as anomalous Hall effect and anomalous Nernst effect, and magneto-optical Kerr effect (MOKE) despite its vanishing magnetization [1-3]. There have been intensive studies of polycrystalline Mn_3Sn film devices. However, MOKE of Mn_3Sn polycrystalline thin film has not been comprehensively reported though it is a powerful tool for probing the dynamics of the magnetic order and magnetic domain. Here we report the significant size of the MOKE signal in polycrystalline Mn_3Sn thin films at room temperature, comparable to those observed in the bulk single crystals.

[1] S. Nakatsuji, N. Kiyohara, & T. Higo, *Nature* **527**, 212–215 (2015)
[2] M. Ikhlas, M., Tomita et al., *Nature Phys.* **13**, 1085–1090 (2017)
[3] T. Higo et al., *Nature Photon.* **12** 73-78(2018)

PS2-14 Light-induced anomalous Hall effect in 3D Dirac semimetal Cd_3As_2 revealed by THz spectroscopy

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A massless Dirac particle consists of a pair of Weyl particles, carrying opposite chiral charges. However, physics of chirality emergent in Dirac semimetals have not been explored well so far. We experimentally show that irradiation by circularly polarized light can create valley chiral charges in a three-dimensional (3D) Dirac semimetal Cd_3As_2, which can be detected through terahertz (THz) anomalous Hall effect. We also find an interesting interaction channel in which a THz electric field modifies the transition probability for particle-hole excitations in an anisotropic manner.

PS2-15

Magnetic hedgehog lattices in itinerant magnets

Shun Okumura

The Institute for Solid State Physics, The University of Tokyo

A three-dimensional topological magnetic texture, called the hedgehog lattice (HL), hosts a periodic array of magnetic monopoles and antimonopoles, which are regarded as sources and sinks of the emergent magnetic field, respectively. While the HLs are experimentally observed in itinerant magnets [1], their stabilization mechanism and topological properties remain elusive. In this study, we numerically investigate the ground state of an effective spin model with long-range interactions arising from the itinerant nature of electrons. We find that HLs can be stabilized in both centrosymmetric and noncentrosymmetric systems at zero field and exhibit topological transitions in a magnetic field [2, 3].

[1] Y. Fujishiro, N. Kanazawa, and Y. Tokura, *Appl. Phys. Lett.* **116**, 090501 (2020)

[2] S. Okumura, S. Hayami, Y. Kato, and Y. Motome, *Phys. Rev. B* **101**, 144416 (2020)

[3] S. Okumura, S. Hayami, Y. Kato, and Y. Motome, *J. Phys. Soc. Jpn.* **91**, 093702 (2022)

PS2-16

Neutron scattering on van der Waals ferromagnet $Fe_{5-x}GeTe_2$

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ISSP. Univ. of Tokyo

Magnetic van der Waals (vdW) compounds have attracted the extensive attention for their spintronic application as well as for the scientific interests in two-dimensional magnetic systems. $Fe_{5-x}GeTe_2$ was reported as the vdW itinerant ferromagnet with the highest transition temperature of 320 K in the vdW magnets [1]. Furthermore, the kink indicating the magnetic transition was observed at 120 K, which is unique behavior in Fe_NGeTe_2 compounds. We carried out the single crystal neutron diffraction and powder inelastic neutron scattering experiment, revealed the detailed magnetic structures, and discussed the spin Hamiltonian of $Fe_{5-x}GeTe_2$.

[1] A. F. May *et al.,* ACS Nano **13**, 4436 (2019).

PS2-17

Inelastic Neutron Scattering Study on a Helimagnet Ni_2InSbO_6

Zheyuan Liu, Yusuke Araki [1], Taka-hisa Arima [1], Shinichi Itoh [2], and Takatsugu Masuda

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In the helimagnet Ni_2InSbO_6 with proper-screw-type spin order [1], soliton lattice was proposed when magnetic field is applied [2]. We performed inelastic neutron scattering on powder Ni_2InSbO_6 at zero magnetic field using HRC @J-PARC to identify the spin Hamiltonian. Well-defined spin-wave excitation is observed with the band energy 20 meV. The spectrum is reproduced by a Heisenberg Hamiltonian using linear spin-wave theory. The magnetic structure of coupled honeycomb lattice was revealed and is consistent with the scenario of soliton lattice proposed by [2]. Dzyaloshinskii-Moriya interaction which induces the helical structure and critical fields of magnetic phase transition, were quantitatively evaluated.

[1] S. A. Ivanov et al., Chem. Mater. **25**, 935 (2013).
[2] Y. Araki et al., Phys. Rev. B **102**, 054409 (2020).

PS2-18

Determination of spin Hall angle in the Weyl ferromagnet Co_2MnGa by taking into account the thermoelectric contributions

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We study the spin Hall effect of Co_2MnGa (CMG) by using the standard spin absorption method. A considerable amount of thermoelectric signal superimposes on the inverse spin Hall signal in the measurement configuration: the applied electric current between the spin injector (permalloy) and bridge (copper) wires produces heating or cooling at the interface via the Peltier effect, which causes an out-of-plane temperature gradient in CMG. As a result, a voltage signal induced by the anomalous Nernst effect of CMG comes into the inverse spin Hall signal. About 75% of the detected signal is found attributable to the thermoelectric effects.

PS2-19

Magnetic field effects on structural domains and magnetism in double perovskite Ba_2MgReO_6

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Ba_2MgReO_6 with an electron configuration of $5d^1$ undergoes phase transitions to a quadrupolar ordered phase at T_q = 33 K and to a canted antiferromagnetic phase at T_m = 18 K [1][2]. As a result, structural and magnetic domains are formed below T_m.
X-ray diffraction experiments in magnetic fields in this study have revealed that structural domains can be aligned by a magnetic field below T_m. Even between T_m and T_q ; there is field- induced change of magnetization in the nonmagnetic quadrupole-ordered phase. These unique magnetic-field effects likely originate from the spin–orbit entangled electronic state of Re 5*d* electrons.

[1] D. Hirai et al., *Phys. Rev. Res.* **2**, 022063 (2020).
[2] D. Hirai et al. *JPSJ* **88**, 064712 (2019).

PS2-20

Theory on transport properties of chiral phonons and its application to α-quartz

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Chirality is a fundamental concept manifesting itself in a wide range of fields. “Chirality” of phonons has recently been attracting interests for its exotic role in e.g. optical transitions and transport phenomena. In this poster, we show chiral phonons driven by temperature gradient have angular momentum and that it can be observed through Einstein-de Haas effect. We apply our theory to a real material α-quartz and give a qualitative estimation. We plan to discuss how the chiral phonons affect conduction electrons. Most interestingly, applied temperature gradient generates spin current via the phonon angular momentum and electron-phonon couplings.

PS2-21

Observation of unoccupied states and topological characterization of Bi(111)

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Bismuth (Bi)—a crucially important component in many topological materials—exhibits various unique physical properties such as gigantic diamagnetism, spin Hall angle, and Nernst effect [1]. While a lot of theoretical studies have shown that these properties are attributed to the strong spin-orbit coupling (SOC) and the three-dimensional Dirac fermions existing at three equivalent L points in momentum space [1], those theoretical calculations fail to explain many experimental properties, including the topology of pure Bi. Because of its small band gap energy and a lack of conclusive evidence, the topological property of pure Bi still remains elusive [2], [3], [4], [5].

In this work, we experimentally determine the band topology of pure Bi by utilizing time-, spin- and angle-resolved photoemission spectroscopy (Tr-SARPES) with the large photon energy (10.7 eV) to cover the full Brillouin zone (BZ) [6]. We directly observed the band structure of the unoccupied states and their spin polarizations of in-situ grown Bi film. By extracting the precise spin polarizations of the two surface states ranging from the zone center to the corner of the BZ, we successfully reveal the possible evidence of topological non-triviality where one branch of the surface state is connected to the bulk conduction band and the other branch is connected to the bulk valence band at the corner of the BZ. Because of the bulk-edge corresponding, we expect that our results on spin-polarized surface band structures will be of great significance in determining the topological state of pure Bi.

[1] Z. Zhu et. al., Phys. Rev. B 84, 115137 (2011).
[2] D. Hsieh et al., Nature 452, 970 (2008).
[3] S. Ito et. al., Phys. Rev. Lett. 117, 236402 (2016).
[4] I. Aguilera et al., Phys. Rev. Mat. 5, L091201 (2021).
[5] C. König et. al., Phys. Rev. B 104, 035127 (2021).
[6] K. Kuroda et. al., JPS, 2021 autumn meeting, 21aE2-7 (2021).

PS2-22

Observation of logarithmic anomaly in the transverse thermoelectric conductivity at low temperature in ferromagnet CoMnSb

Hiroto Nakamura, Susumu Minami, Takahiro Tomita, Agustinus Agung Nugroho, and Satoru Nakatsuji
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In the topological ferromagnet with large anomalous Nernst effect like Co_2MnGa, the transverse thermoelectric conductivity α_{yx} is significantly enhanced and shows an unconventional logarithmic temperature dependence[1]. Here, we report a similar behavior observed from as low as 20 K to 300 K in ferromagnet CoMnSb[2]. Our experimental study of the transport phenomena using single-crystalline samples coincides with the prediction by the first-principles calculation. Furthermore, the Weyl nodes are suggested near the sample's Fermi level and the distance between them is comparable to the energy scale of the crossover temperature between the unconventional feature of α_{yx} and the Mott relation.

[1] A. Sakai *et al., Nat. Phys.* **14**, 1119 (2018).
[2] H. Nakamura *et al., Phys. Rev. B* **104**, L161114 (2021).

PS2-23

Development of the simultaneous measurement system of four-point-probe electrical transport and tunneling spectroscopy

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To depict a solid picture of superconductivity in atomic layers or thin films, we develop an apparatus that enables the simultaneous in situ measurements of electrical transport and tunneling spectroscopy. It was difficult to conduct them on the same sample because the former requires a conducting substrate for the current's return path, which impairs the accuracy of the latter. This conflict is solved by using four-point transport probe for tunneling spectroscopy; one probe not forming a tunnel junction is directly attached to the sample to ensure the return path, thereby enabling us to measure samples even on highly insulating substrates.

PS2-24 Experimental Study of Surface States in Superfluid Helium 3-B phase

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Department of Physics, The University of Tokyo

Superfluid ^{3}He-B provides an opportune plaNorm for research of topological maOers. On the free surface, topological aspects appear such as the gap suppression. The spaQal change of the density of states causes the Andreev reflecQon, and the reflecQon rate has been theoreQcally elucidated at various incident angles in superfluid ^{3}He-B [1]. In a previous study using a blackbody radiator type device that can inject quasiparQcles into a superfluid surface, the Andreev reflecQon was measured at a fixed angle [2] . We have proceeded with this experiment, and developed an angle-resolved detector and a Monte Carlo simulator to analyze it.

[1] Y. Nagato, M. Yamamoto, and K. Nagai, J. Low Temp. Phys. **110**, 1135(1998).
[2] T. Okuda, H. Ikegami, H. Akimoto, and H. Ishimoto, Phys. Rev. LeO. **80**, 2857(1998).

PS2-25 Physical properties of polycrystalline Mn_3Sn films deposited by molecular beam epitaxy

Mihiro Asakura [1], Tomoya Higo [1,2,3], Daisuke Nishio-Hamane [3], Shoya Sakamoto [3], Shinji Miwa [2,3,4], and Satoru Nakatsuji [1,2,3,4,5]

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The noncollinear antiferromagnet Mn_3Sn exhibiting large responses like the anomalous Hall effect [1] is a promising material in antiferromagnetic spintronics [2]. Although magnetron sputtering has been widely used to prepare Mn_3Sn films, perpendicular switching of the cluster magnetic octupole was recently observed in epitaxial Mn_3Sn films grown by molecular beam epitaxy (MBE) [3]. The films had a large magnetic domain and an epitaxial in-plane strain, and it indicates the quality of the films can be greatly improved by this deposition technique. In this presentation, the properties of MBE-grown polycrystalline Mn_3Sn films with relatively small surface roughness will be discussed.

[1] S. Nakatsuji *et. al., Nature* **527**, 212 (2015)
[2] T. Jungwirth *et. al., Nat. Nanotechnol.* **11**, 231 (2016)
[3] T. Higo, K. Kondou *et. al., Nature* **607**, 474 (2022)

PS2-26

Optically driven rotation of exciton-polariton condensates

Yago del Valle Inclan Redondo [1,2], Christian Schneider [3], Sebastian Klembt [4], Sven Höfling [4], Seigo Tarucha[1], and Michael D. Fraser [1,2]

[1] RIKEN Center for Emergent Matter Science, [2] Physics & Informatics Laboratories (PHI Lab), NTT Research, [3] Institute of Physics, University of Oldenburg, [4] Technische Physik, Physikalisches Institut and Wilhelm Conrad Roentgen-Research Center for Complex Material System, Universität Würzburg

A Bose-Einstein condensate of exciton-polaritons, hybrid light-matter quasi-particles, may be formed by optically pumping a high quality semiconductor microcavity. Studying the polariton superfluid response to rotation is challenging however, as microwave frequencies are required to nucleate significant angular momentum. We drive rotation of a spontaneously formed polariton condensate by pumping with the time-dependent interference of two structured, GHz frequency-offset laser modes [1]. The incorporation of angular momentum is directly measured and found to result from a non-Hermitian mechanism. Via numerical simulations, this system is shown to be suitable for the study of dense quantized vortex matter in a non-equilibrium regime.

[1] Y. dV. I. Redondo, C. Schneider, S. Klembt, S. Höfling, S. Tarucha and M. D. Fraser "Optically driven rotation of a exciton-polariton condensates" *arXiv:2209.01904* (2022)

PS2-27

Phase diagram of anisotropic triangular strip spin model

Tatsuki Odake

The Institute for Solid State Physics, The University of Tokyo

In our presentation, we will talk about the properties of the ground state of the quantum antiferromagnets on anisotropic triangular strip [1]. We analyzed the model by the density matrix renormalization group (DMRG) method. When the rung coupling is small compared to the ladder coupling, the ground state of the ATS model become gapless symmetry-protected topological (SPT) state, in that there is even-fold degeneracy of entanglement spectrum and the central charge of the model become one. Moreover, the ground state become ferrimagnetic state or gapless trivial state in other region of parameters.

[1] Y. Hidaka et al. arXiv:2205.15525 (2022).

PS2-28

Tensor network ansatz for the quantum many-body models

Wei-Lin Tu
Korea University

In our nature, the macroscopic behavior of the materials is often explained by its microscopic properties, which give rise to various many-body models. However, to analytically solve these models in the thermodynamic limit is usually a difficult task. On the other hand, by exploiting the capability of modern computational devices an effective "ansatz" can be constructed who serves as a good approximation for the target model. In this talk, I am going to demonstrate how theorists can adopt the tensor network algorithm as the tool in realizing the ground state or excited state ansatz for a quantum many-body system. Utilizing the infinite projected entangled-pair state (iPEPS) we get to study the physics of various systems in two dimensions, such as a frustrated or dipolar artificial magnet in an optical lattice [1,2] and the real-world quantum magnetism [3,4]. Besides the ground state, by summing up various tensor graphs an effective low-energy excited state ansatz can also be probed and computationally simplified using the mathematical generating function with back propagation [5]. I hope that my brief introduction and examples provided here can arouse a wider attention in adopting this algorithm of good potential in various aspects.

[1] Wei-Lin Tu, Huan-Kuang Wu, and Takafumi Suzuki, *Journal of Physics: Condensed Matter* **32**, 455401 (2020).

[2] Huan-Kuang Wu and Wei-Lin Tu, *Physical Review A* **102**, 053306 (2020).

[3] Wei-Lin Tu, Eun-Gook Moon, Kwan-Woo Lee, Warren E. Pickett, and Hyun-Yong Lee, *Communications Physics* **5**, 130 (2022).

[4] Wei-Lin Tu, Xinliang Lyu, S. R. Ghazanfari, Huan-Kuang Wu, Hyun-Yong Lee, and Naoki Kawashima, arXiv:2204.01197 (2022).

[5] Wei-Lin Tu, Huan-Kuang Wu, Norbert Schuch, Naoki Kawashima, and Ji-Yao Chen, *Physical Review B* **103**, 205155 (2021).

PS2-29

Effects of Mn-doping in Mn_3Sn on the Phase Transitions and Transport Properties near Criticality

Yuki Koike
The University of Tokyo

Mn_3Sn is the first realized example of an antiferromagnetic Weyl semimetal, and has been shown to have colossal anomalous transport properties beyond what can be explained by its magnetization [1]. The size of the Berry phase, which is the origin of such colossal transports, is heavily dependent on the material's spin structure [2], and thus an accurate understanding of the phase diagram is essential for further applications. We build on previous research [3] to fill in crucial gaps in the known binary phase diagram, as well as studying the transport properties near criticality.

[1] Nakatsuji, S., Kiyohara, N., & Higo, T., *Nature* **527**, 7577 (2015)
[2] Song, Y., Hao, Y., Wang, S., Zhang, J., Huang, Q., Xing, X., & Chen, J. (2020). *Physical Review B* **101**, 14 (2020)
[3] Muhammad, I., Tomita, T., & Nakatsuji, S., JPS Conf. Proc. **30**, 011177 (2020)

PS2-30

Schrödinger representation of quantum mechanics, Berry connection, and superconductivity

Hiroyasu Koizumi
Center for computational sciences, University of Tsukuba

The standard quantum mechanical electronic state calculations for molecules and solids use the Schrödinger representation where the momentum conjugate to the coordinate is represented by a derivative of it. This formalism contains an extra U(1) phase degree-of-freedom, which has been ignored so far.
We show that it can be regarded as a Berry phase arising from many-electron interaction, and when it is non-trivial, it gives rise to a current carrying ground state identified as the superconducting ground state. It is shown that this superconducting state is connected to the BCS one, and captures the experimentally verified results.
However, there are gratifying differences that removes the shortcomings of the BCS theory; the ground state is particle-number-conserving, and the mass appearing in the London moment phenomenon is the free electron mass.
The present work indicates that the appearance of this non-trivial U(1) phase is the cause of superconductivity rather than the electron pairing on which the BCS theory is based.

[1] H. Koizumi, *Phys. Lett. A* **450**, 128367 (2022)

PS2-31 One-loop perturbativity bound in single-field inflation

Jason Kristiano
RESCEU, The University of Tokyo

Quantum fluctuations stretched by cosmic inflation is currently the leading theory to explain the origin of cosmic microwave background (CMB) anisotropy and large-scale structure (LSS). However, the physical mechanism of inflation is still unknown. While top-down approach to realize inflation from a unified theory still suffers some challenges, bottom-up approach seems more promising. Starting from the most general inflation model, we can shrink the parameter space by observational and theoretical constraints. In this poster, I will show that requiring one-loop perturbativity to the fluctuations power spectrum leads to a constrain on inflationary parameter space [1,2].

[1] J. Kristiano and J. Yokoyama, *JCAP* **07** (2022) 007.
[2] J. Kristiano and J. Yokoyama, *Phys. Rev. Lett.* **128**, 061301 (2022).

PS2-32 Foliated-exotic duality in fractonic BF theories

Shutaro Shimamura
The University of Tokyo

A Fracton phase is a new kind of phase of matter that exhibits excitations with restricted mobility. There has been proposed two continuum descriptions of fracton systems: foliated quantum field theories (FQFTs) and exotic quantum field theories. We discuss a duality between these two types of fractonic BF theories in $3 + 1$ dimensions [1,2], both of which are the continuum descriptions of the X-cube model [3]. By matching the gauge-invariant operators, we find the explicit correspondences of the gauge fields, parameters and allowed singularities and discontinuities.

[1] K. Slagle, “Foliated Quantum Field Theory of Fracton Order,” Phys. Rev. Lett. 126 no. 10, (2021) 101603, arXiv:2008.03852 [hep-th].
[2] N. Seiberg and S.-H. Shao, “Exotic ZN symmetries, duality, and fractons in 3+1-dimensional quantum field theory,” SciPost Phys. 10 no. 1, (2021) 003, arXiv:2004.06115 [cond-mat.str-el].
[3] S. Vijay, J. Haah, and L. Fu, “Fracton Topological Order, Generalized Lattice Gauge Theory and Duality,” Phys. Rev. B 94 no. 23, (2016) 235157, arXiv:1603.04442 [cond-mat.str-el].

PS2-33 Conformal field theories and error correcting codes

Shinichiro Yahagi
Department of Physics, The University of Tokyo

A conformal field theory (CFT) with toroidal compactification is used to describe a compactified spacetime in string theory. On the other hand, an error correcting code is a concept in information theory for transmitting information correctly. The relation between CFTs and classical binary codes is well known and has recently been extended to quantum codes [1]. We construct CFTs from codes on finite fields through lattices [2]. Using this correspondence, we can relate properties in both theories and calculate them efficiently such as the spectral gap of CFT and the error correction capability of code.

[1] A. Dymarsky & A. Shapere, *J. High Energ. Phys.* **2021**, 160 (2021)
[2] S. Yahagi, *J. High Energ. Phys.* **2022**, 58 (2022)

PS2-34 Measurement of muon-induced nuclear transmutation for Si isotopes

Rurie Mizuno
Department of Physics, The University of Tokyo.

The muon capture reaction is a capture of a negative muon by a proton in the nucleus via the weak interaction. This reaction transmutes the original nucleus and populates excited states. The measurement data of the reaction are sparse, and there is no established model. To obtain accurate data and investigate the excitation state of the nuclei after the muon capture, we measured the absolute production branching ratio of each daughter nucleus produced by the muon capture of Si isotopes at MLF, J-PARC. The result of the experiment will be reported in this poster session.

PS2-35

Truly chiral phonons in α-HgS

Kyosuke Ishito
Department of Physics, Tokyo Institute of Technology

Recently, phonons with chirality (chiral phonons) have attracted much attention. Chiral phonons have angular momentum and pseudo-angular momentum [1]. In circularly polarized Raman scattering spectroscopy with backscattering along the helical axis of a helical crystal, the doubly-degenerated Γ_3 mode peaks split [2]. In addition, each of the two split peaks is observed under two different conditions where the angular momentum of the incident circular polarization is reversed [2]. In this work, we experimentally verified the conservation law between the pseudo-angular momentum of the circular polarizations and the phonon [3].

[1] L. Zhang and Q. Niu, *Phys. Rev. Lett.* **115**, 115502 (2015).
[2] A. S. Pine and G. Dresselhaus, *Phys. Rev.* **188**, 1489 (1969).
[3] K. Ishito, H. Mao, Y. Kousaka, Y. Togawa, S. Iwasaki, T. Zhang, S. Murakami, J. Kishine, and T. Satoh, *arXiv,* 2110.11604 (2021).

PS2-36

Numerically “exact” simulation of quantum Carnot cycle: Dynamics and thermodynamics

Shoki Koyanagi
Kyoto University

Though there are many studies regarding quantum thermodynamics, there are only a few studies in which strong interaction between the system and the heat bath is considered. In our study, we introduce quasi-static Helmholtz energy [1], and define thermodynamical quantities, such as magnetic susceptibility, by differentiating the energy [2]. To study the quantities’ behavior, we employ spin-boson model, and conduct numerical calculations of quantum Carnot cycle in quasi-static, non-Markovian and strong system-bath interaction regime [3]. We show magnetic field–magnetic susceptibility diagram as the pressure – volume diagram in classical Carnot cycle.

[1] S. Sakamoto and Y.Tanimura, J. Chem. Phys. **153**, 234107 (2020)
[2] S. Koyanagi and Y. Tanimura, J. Chem. Phys. **157**, 014104 (2022)
[3] S. Koyanagi and Y. Tanimura, J. Chem. Phys. **157**, 084110 (2022)

PS2-37 Rydberg Atom Interactions with an Optical Nanofiber

Alexey Vylegzhanin
Light-Matter Interactions for Quantum Technologies Unit, Okinawa Institute of Science and Technology

Cold Rydberg atoms have become a promising platform for quantum information [1] and quantum simulations due to their exotic properties. Optical nanofibers (ONF) are an excellent tool to interact with such atoms due to the strong evanescent field [2]. We exploit a two-photon ladder-type excitation in by using 780 nm Magneto-Optical Trap (MOT) cooling lasers and 480 nm light from the evanescent field of an ONF and observe it by collecting a fluorescence signal. We obtain excitation spectra from $5S_{1/2}$ to $nS_{1/2}$, $nD_{3/2}$ and $nD_{5/2}$ Rydberg states for a wide range of principal quantum number, n, states.

[1] M. Saffman, Rev. Mod. Phys. **82**, 2313 (2010)
[2] K.P. Nayak, Opt. Express **15**, 5431-5438 (2007)

PS2-38 Time-Efficient Constant-Space-Overhead Fault-Tolerant Quantum Computation

Hayata Yamasaki
Department of Physics, Graduate School of Science, The University of Tokyo

Scalable realization of quantum computing requires fault tolerance. Conventionally, protocols for fault-tolerant quantum computation (FTQC) demand excessive space overhead of physical qubits per logical qubit. A more recent protocol to achieve constant-space-overhead FTQC using quantum low-density parity-check (LDPC) codes thus attracts considerable attention but suffers from another drawback: polynomially long time overhead. We introduce an alternative approach to constant-space-overhead FTQC using a concatenation of multiple small-size quantum codes, rather than a single large-size quantum LDPC code, to achieve constant space overhead and only quasi-polylogarithmic time overhead simultaneously. This opens a promising avenue for the low-overhead FTQC based on code concatenation.

PS2-39

Reversing unknown qubit-unitary operation, deterministically and exactly

Satoshi Yoshida
Department of Physics, Graduate School of Science, The University of Tokyo

We report a deterministic and exact protocol to reverse a qubit-unitary operation given as an unknown oracle. We derive the Choi matrix representing a quantum circuit transforming four calls of a qubit-unitary operation into its inverse operation by imposing the SU(2)×SU(2) symmetry on the Choi matrix. We also present the semidefinite programming to search deterministic exact unitary inversion for an arbitrary dimension. The large search space including all possible protocols is reduced to the space of the Choi matrices with the SU(d)×SU(d) symmetry.

PS2-40

Universal Scaling Bounds on a Quantum Heat Current

Shunsuke Kamimura
University of Tsukuba, AIST

We derived scaling bounds on a heat current flowing into an L-particle open quantum system, which is exploited to obtain a quantum-enhanced heat engine performance [1,2]. The best achievable scaling about L is found to be L^3 in a limit of large L, which can be saturated by an L- body interaction between the particles. We also found another scaling bound L^2 for more feasible cases, which can be saturated for superradiance. Our results are useful not only to understand fundamental features of quantum systems, but also to seek industrial applications of quantum technology [3].

[1] H. Tajima and K. Funo, PRL **127**, 190604 (2021).
[2] SK, H. Hakoshima, Y. Matsuzaki, K. Yoshida, and Y. Tokura, PRL **128**, 180602 (2022).
[3] SK, K. Yoshida, Y. Tokura, and Y. Matsuzaki, arXiv:2209.05789 (2022).0 (2022)

DAY 4

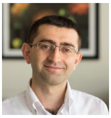
FRIDAY,
NOVEMBER 11, 2022

SESSION 7

NONEQUILIBRIUM AND EMERGING PARTICLES

Chair: R. Shimano (U. Tokyo)

Ultrafast Charge Order Dynamics in a Kagome Metal



PLENARY SPEAKERS

Nuh Gedik

MIT

The recently discovered group of topological superconducting kagome metals, AV_3Sb_5 (A = K, Rb, Cs), host complex electronic phases. One of these is the charge density wave (CDW) phase which has been extensively studied recently. However, the nature of this phase and its relation to other orders is still not well understood. In my talk, I will present recent results in which we used time- and angle- resolved photoemission spectroscopy to investigate the CDW phase of CsV_3Sb_5. After excitation with an ultrafast laser pulse, we obtained an energy-momentum resolved tomographic movie of the band structure. Our data directly yields the melting time of the CDW gap. Furthermore, we also observe weak oscillations of the in-gap intensity during its recovery. Our experimental results distinguish these modes from the phonon modes, and using DFT calculations, we show that they correspond to the collective excitations of the order parameter. These results provide important clues towards understanding the mechanism of charge order in these materials.

Floquet engineering and topological nonlinear optics

INVITED SPEAKERS

Takashi Oka

ISSP, The University of Tokyo

Geometric effects in non-equilibrium systems driven by external fields are currently being studied very actively. Dirac electrons driven by a laser electric field can be studied experimentally and theoretically, making it an ideal system for investigating unknown non-equilibrium phenomena. In this talk, I will explain phenomena such as Floquet-Weyl semimetals, geometric effects in quantum tunneling (twisted Landau-Zener tunneling) and their outcomes.

Terahertz anomalous Hall effect dynamics in Weyl antiferromagnet

INVITED SPEAKERS

Ryusuke Matsunaga

The Institute for Solid State Physics, The University of Tokyo

The noncollinear antiferromagnet Mn_3Sn hosts Weyl fermions in the frustrated Kagome bilayer and shows a giant anomalous Hall effect (AHE) at room temperature, which promises to constitute high-speed spintronic devices in terahertz (10^{12} Hz) frequency. To realize the current-based fast readout of the antiferromagnetic order, we have investigated how the giant AHE behaves in the picosecond (10^{-12} s) time scale [1,2]. Nonequilibrium dynamics of Mn_3Sn studied by ultrafast terahertz spectroscopy will be presented.

[1] T. Matsuda, RM et al., Nature Commun. 11, 909 (2020).
[2] T. Matsuda, RM et al., arXiv:2206.06627

Theoretical studies of photoinduced topological phase transitions in organic salt α-(BEDT-TTF)$_2$I$_3$

CONTRIBUTED SPEAKERS

Keisuke Kitayama [1], Masao Ogata [1], Yasuhiro Tanaka [2], and Masahito Mochizuki [2]

[1] The University of Tokyo, [2] Waseda University

Optical controls of topologies in matters have been intensively studied recently. However, materials targeted by the research are still limited, and it is greatly demanded to widen the research targets for development of this field. In this talk, we will discuss our recent studies that predicted novel phenomena in photodriven organic salt α-(BEDT-TTF)$_2$I$_3$. The topics are the following, (1) Topological phase transition induced by circularly polarized light [1], (2) Pair annihilation of emergent magnetic charges induced by linearly polarized light [2], (3) Novel type of photoinduced topological phase transition accompanied by collision and collapse of Dirac points induced by elliptically polarized light [3].

[1] K. Kitayama and M. Mochizuki, Phys. Rev. Res. **2**, 023229 (2020).
[2] K. Kitayama, M. Mochizuki, Y. Tanaka, and M. Ogata, Phys. Rev. B **104**, 075127 (2021).
[3] K. Kitayama, M. Ogata, M. Mochizuki, and Y. Tanaka, arXiv:2203.04539.

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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 highspeed 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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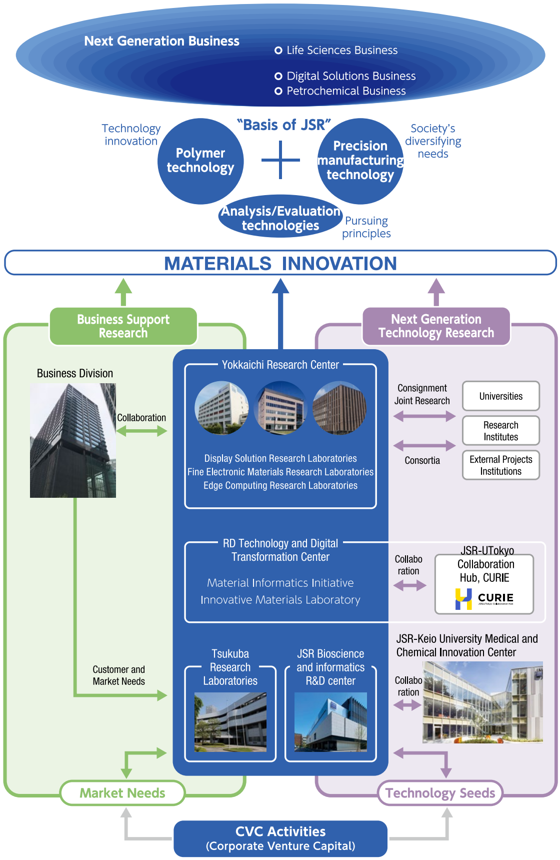

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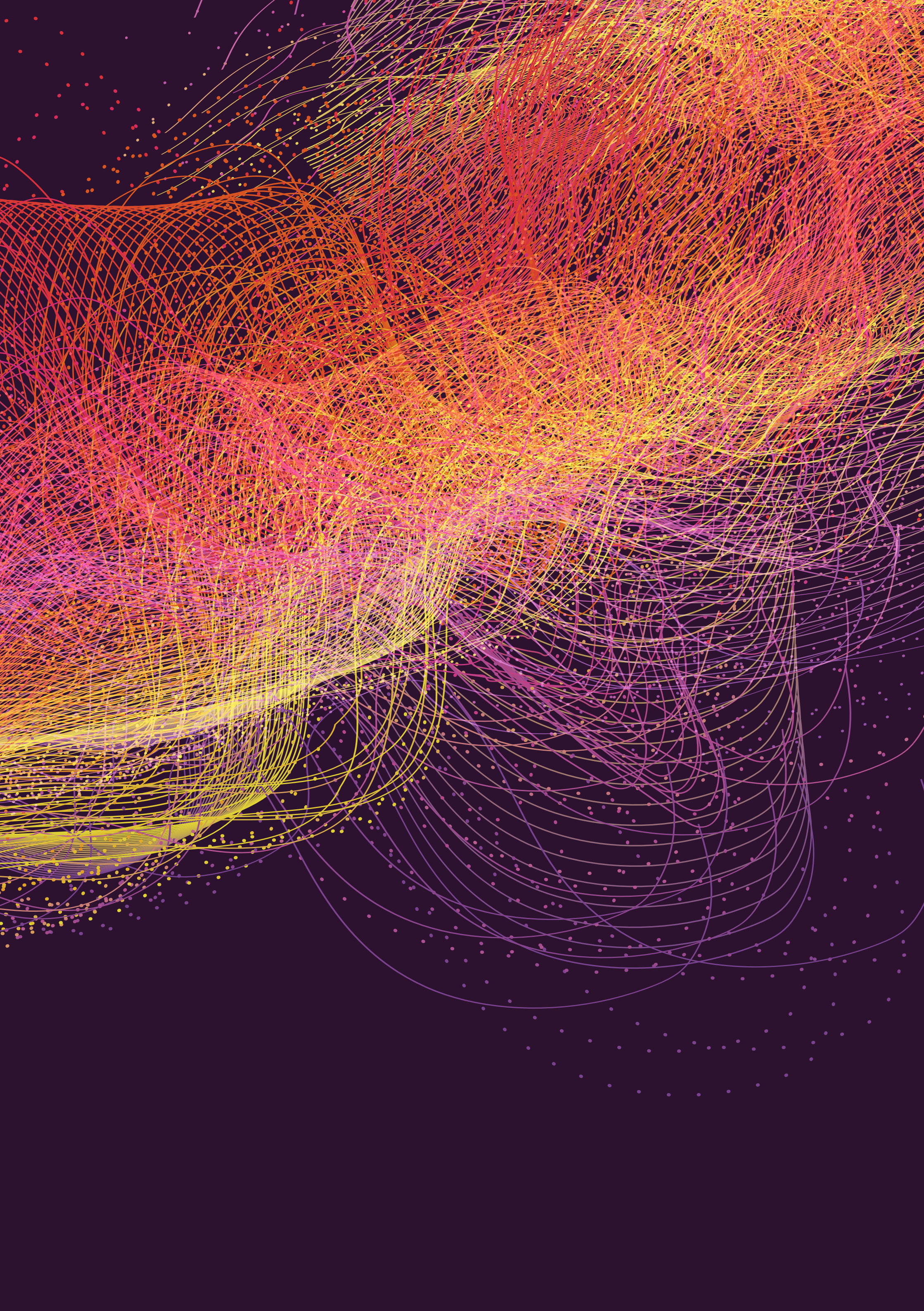

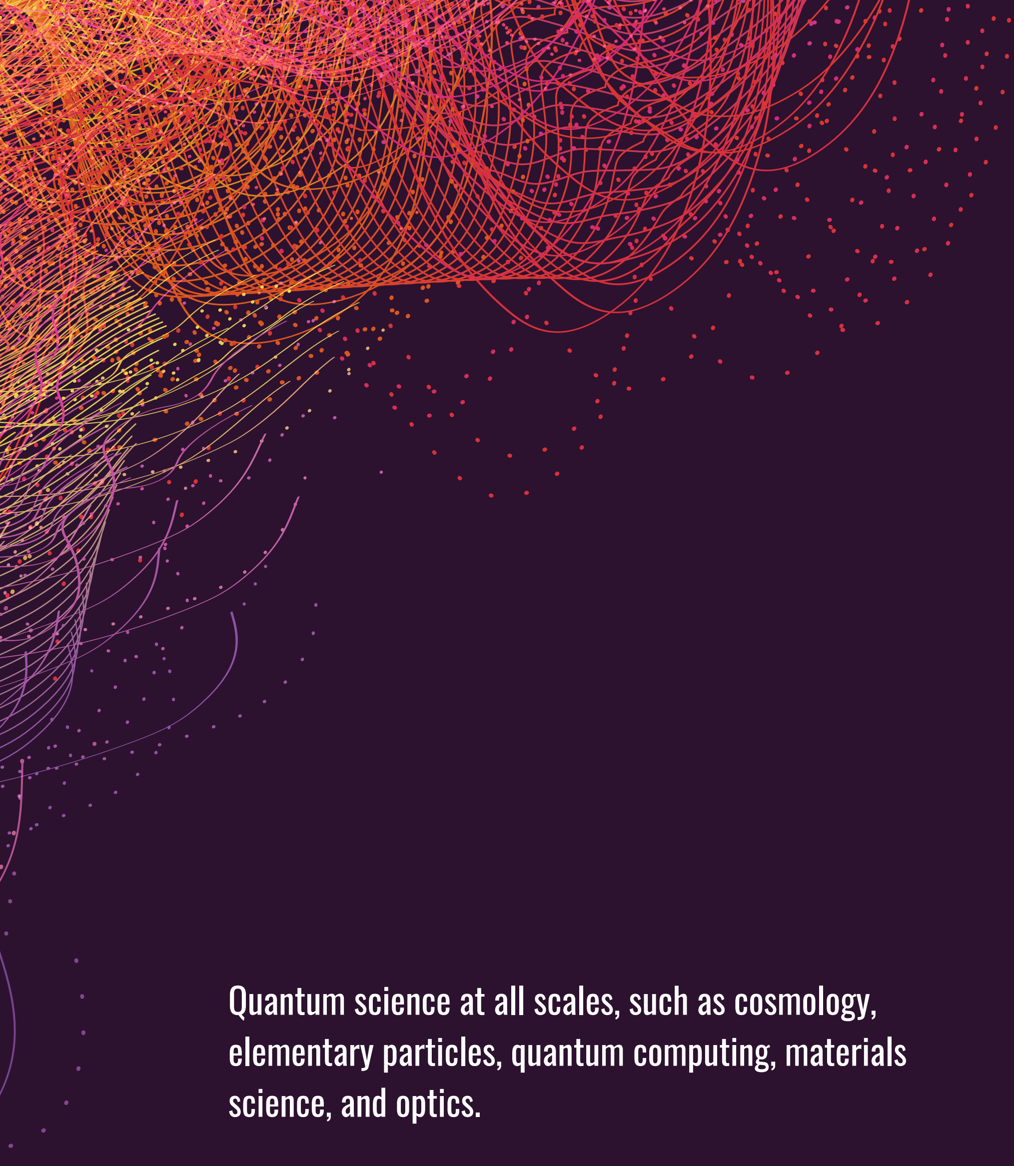

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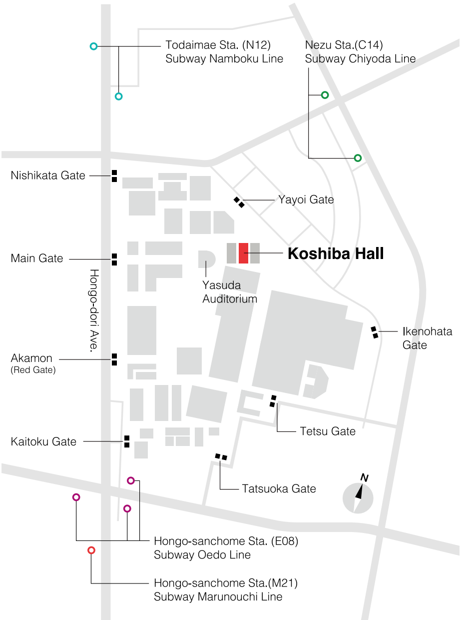

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