“Topological Phases and Functionality of Correlated Electron Systems” (TPFC2019)

18th – 20th Feb, 2019

Kashiwanoha Campus Station Satellite,

The University of Tokyo, Kashiwa, Japan

Scope:

For a long time, magnetism has been a central subject in strongly correlated electron systems. More recently, topology led to a new classification of band insulators, namely topological insulators. Where magnetism and topology meet, we find many intriguing phenomena including emergent "relativistic" particles and multipolar degrees of freedom. The novel physics also opens up a promising direction in spintronics and other potentially practical applications. In this conference, we will explore experimental and theoretical studies on subjects ranging from fundamental issues in correlated topological phases to their cutting-edge applications to spintronics.

Organizers:

Satoru Nakatsuji	Institute for Solid State Physics, The University of Tokyo
Yoshichika Otani	Institute for Solid State Physics, The University of Tokyo
Masaki Oshikawa	Institute for Solid State Physics, The University of Tokyo
Collin Broholm	Johns Hopkins University
Hisatomo Harima	Kobe University
Shinji Miwa	Institute for Solid State Physics, The University of Tokyo
Hiroki Wadati	Institute for Solid State Physics, The University of Tokyo

Supported by

Institute for Solid State Physics, The University of Tokyo
J-Physics: Physics of Conductive Multipole Systems
Nano Spin Conversion Science
CREST
Johns Hopkins University

PROGRAM OF WORKSHOP

Feb. 18 (Mon.)

09:15-10:00	Registration	
Opeing (Chair: S. Nakatsuji)		
10:00-10:20	**Opening announcement**, S. Nakatsuji **Opening remarks**, H. Mori	
Session 1: Topological phases (Chair: L. Balents)		
10:20-10:50	(O18-1) **K. L. Wang** Univ. of California	Topological Transitions and Chiral Majorana Fermion
10:50-11:20	(O18-2) **Y. Tokura** RIKEN Center for Emergent Matter Science (CEMS)	Emergent magneto-transport phenomena in strongly correlated topological phase
11:20-11:45	(O18-3) **T. Tomita** ISSP, The Univ. of Tokyo	Topological Nature and Anomalous Nernst effect in Magnetic Weyl Metals
11:45-12:10	(O18-4) **T. Kondo** ISSP, The Univ. of Tokyo	Discovery of weak topological insulator state in quasi-one-dimensional bismuth iodide
12:10-14:00	Lunch	
Session 2: Dynamics in quantum spin liquids (Chair: C. Broholm)		
14:00-14:30	(O18-5) **L. Balents** Kavli Inst. of Theoretical Physics, Univ. of California	Dynamics and transport in quantum magnets
14:30-15:00	(O18-6) **H. Mori** ISSP, The Univ. of Tokyo	Proton-dynamics Coupled Quantum Spin Liquid State and Magnetic Switching in Organic Mott System

15:00-15:30	(O18-7) **N. Drichko** Johns Hopkins Univ.	The quantum dipole liquid in triangular lattice molecular Mott insulators and its relevance to a spin liquid
15:30-15:55	(O18-8) **Y. Tada** ISSP, The Univ. of Tokyo	Theory of proton-driven quantum spin-dipole liquid
15:55-16:25	Coffee break	

Session 3: Metal spintronics (Chair: T. Jungwirth)

16:25-16:55	(O18-9) **S. Yuasa** Natl. Inst. of Advanced Industrial Science and Technology	Voltage control of magnetic anisotropy and its application to voltage-torque MRAM
16:55-17:20	(O18-10) **S. Miwa** ISSP, The Univ. of Tokyo	Electric-field-induced change of perpendicular magnetic anisotropy at metal/dielectric interface
17:20-17:45	(O18-11) **K. Yamamoto** ISSP, The Univ. of Tokyo	Ultrafast demagnetization in Pt-containing ferromagnetic thin films probed by x-ray free electron laser

Feb. 19 (Tue.)

Session 4: Topological spintronics (Chair: YC. Otani)

09:00-09:30	(O19-1) **A. H. MacDonald** Physics Dept., Univ. of Texas at Austin	Magic Angle Twisted Bilayer Graphene
09:30-10:00	(O19-2) **R. Arita** Dept. of Applied Physics, The Univ. of Tokyo	Anomalous transverse transport and domain wall motion in non-collinear antiferromagnets
10:00-10:30	Coffee break	

Session 5: Antiferromagnetic spintronics (Chair: A. H. MacDonald)		
10:30-11:00	(O19-3) **T. Jungwirth** Inst. of Physics, Academy of Sciences of the Czech Republic	Crystal symmetries and transport phenomena in antiferromagnets
11:00-11:25	(O19-4) **T. Higo** ISSP, The Univ. of Tokyo	Large time-reversal-odd responses in the Weyl antiferromagnet Mn_3Sn bulk and thin film for antiferromagnetic spintronics
11:25-11:50	(O19-5) **K. Kondou** RIKEN Center for Emergent Matter Science (CEMS)	Observation of magnetic spin Hall effect and magnetic inverse spin Hall effect in a chiral antiferromagnet Mn_3Sn

Poster session (Chair: S. Miwa)		
11:50-13:50	**Photo** **Poster preview**	 (Lunch box provided),
13:50-15:50	**Poster presentation**	
15:50-16:20	Coffee break	

Session 6: Excitations in quantum spin liquids (Chair: O. Tchernyshyov)		
16:20-16:50	(O19-6) **Y. Matsuda** Dept. of Physics, Kyoto Univ.	Majorana fermions and half-integer thermal quantum Hall effect in a quantum spin liquid
16:50-17:15	(O19-7) **M. Yamashita** ISSP, The Univ. of Tokyo	Spin Thermal Hall Conductivity of a Kagomé Antiferromagnet
17:15-17:40	(O19-8) **D. Hirai** ISSP, The Univ. of Tokyo	Gapless spin liquid in the anisotropic triangular lattice antiferromagnet $A_3ReO_5Cl_2$ (A = Ca, Sr, Ba)
18:30-	Conference dinner (MC: H. Wadati)	

Feb. 20 (Wed.)

Session 7: Topological and chiral magnets (Chair: N. P. Armitage)		
09:00-09:30	(O20-1) **N. Nagaosa** RIKEN Center for Emergent Matter Science (CEMS)	Nonreciprocal transport in quantum materials
09:30-10:00	(O20-2) **K. Kaneko** Materials Sciences Research Center, Japan Atomic Energy Agency	Skyrmion lattice in f-electron magnet EuPtSi
10:00-10:25	(O20-3) **T. Sakakibara** ISSP, The Univ. of Tokyo	Magnetization of the skyrmion lattice phase and field-induced tricritical point in EuPtSi
10:25-10:55	Coffee break	

Session 8: Multipolar Kondo systems (Chair: H. Harima)		
10:55-11:25	(O20-4) **Y. B. Kim** Dept. of Physics, Univ. of Toronto	Theory of Multipolar Order and Multipolar Kondo Effect
11:25-11:55	(O20-5) **M. Takigawa** ISSP, The Univ. of Tokyo	Field-induced switching of ferro-quadrupole order parameters in $PrTi_2Al_{20}$
11:55-14:00	Lunch	

Session 9: Quantum criticality and superconductivity (Chair: Y. Matsuda)		
14:00-14:30	(O20-6) **C. Broholm** Johns Hopkins Univ.	Incommensurate magnetism in heavy fermion systems
14:30-15:00	(O20-7) **C. Hicks** Max Planck Inst. for Chemical Physics of Solids	Evaluation of chiral superconductivity in Sr_2RuO_4

15:00-15:30	Coffee break	

Session 10: Spin currents and dynamics (Chair: Y. B. Kim)		
15:30-16:00	(O20-8) **E. Saitoh** Dept. of Applied Physics, The Univ. of Tokyo	Spin current in quantum spin liquids and superconductions
16:00-16:30	(O20-9) **O. Tchernyshyov** Inst. for Quantum Matter and Dept. of Physics and Astronomy, Johns Hopkins Univ.	Mapping the *XY* ferromagnet in d=2+1 onto electrodynamics
16:30-17:00	(O20-10) **N. P. Armitage** ISSP, The Univ. of Tokyo	Shining (THz) light on quantum magnetic systems

Closing (Chair: M. Oshikawa)		
17:00-	**Poster awards** **Closing remarks**, M. Oshikawa	

List of Poster Presentations (Feb. 19, 13:50-15:50)

P01 **M. Akazawa** ISSP, The Univ. of Tokyo
Thermal transport properties of S = 1/2 kagome frustrated Cd-kapellasite

P02 **Y. Asaka** Dept. Eng. Sci., Univ. of Electro-communications
Spin-density-wave transition and Seebeck coefficient in quasi-one-dimensional organic conductors

P03 **Y. Awashima** Dept. of Eng. Sci., Univ. of Electro-Communications
Theoretical study on magnetoresistance of $SrTiO_3$

P04 **C. Bareille** ISSP, The Univ. of Tokyo
Strongly anisotropic high temperature Fermi surface of the Kondo semimetal CeNiSn revealed by ARPES

P05 **H. Chono** Dept. of Physics, Kyoto Univ.
Laser-induced topological phase transitions in bilayer transition metal dichalcogenides

P06 **A. Daido** Kyoto Univ.
Local Magnetic Quadrupole Moments in Insulators

P07 **T. Fujii** Graduate School of Material Science, Univ. of Hyogo
^{31}P-NMR study of pressure induced semiconductor – semimetal transition in Black Phosphorus

P08 **Y. Fujishiro** Dept. of Applied Physics, The Univ. of Tokyo
Transitions of topological spin textures between skyrmion- and hedgehog-lattice states in cubic chiral magnets $MnSi_{1-x}Ge_x$

P09 **H. Fujita** ISSP, The Univ. of Tokyo
Topological lightwaves for optical physics

P10 **S. Furukawa** Dept. of Physics, The Univ. of Tokyo
Dzyaloshinskii-Moriya interactions in volborthite: magnetic orders and thermal Hall effect

P11 **I. Hase** AIST, Japan
Flat-Band Compound as a Possible Candidate of Topological Material

P12 **D. Hirai** ISSP, The Univ. of Tokyo
Spin-orbit coupled insulator Ba_2MgReO_6

P13 **M. Hirschberger** RIKEN Center for Emergent Matter Science
Skyrmion formation in centrosymmetric materials

P14 **M. Hosoi** Dept. of Phys., The Univ. of Tokyo
Multipolar DM interaction in 5d electron systems

P15 **S. Iimura** Dept. of Phys., Saitama Univ.
Mechanism of superconductivity in Kondo lattice with semi-metallic conduction bands

P16 **Y. Ikeda** Kyoto Univ.
Supercurrent-induced Edelstein effect

P17 **A. Ikeda** ISSP, The Univ. of Tokyo
Excitonic condensation in correlated cobaltite $LaCoO_3$ at ultrahigh magnetic field

P18 **M. Ikhlas** ISSP, The Univ. of Tokyo
Magnetic Phases of Non-collinear Antiferromagnet Mn_3Sn

P19 **H. Ishizuka** Dept. of Applied Physics, The Univ. of Tokyo
Rectification of Spin Current in Magnetic Insulators with Linearly-Polarized Electromagnetic Waves

P20 **T. Isomae** ISSP, The Univ. of Tokyo
NQR Study of Multipole orders in PrT_2Al_{20} (T=Ti, V)

P21 **Y. Izaki** Dept. Eng. Sci, U. Electro-Communications
Anomalous Zeeman effect in strongly spin-orbit coupled systems

P22 **R. Kadono** Inst. Mater. Struct. Sci., KEK
Coupled Spin-Charge Fluctuation in the Semimetal Phase of All-In/All-Out Antiferromagnet $Cd_2Os_2O_7$

P23 **S. Kanasugi** Kyoto Univ.
Spin-orbit-coupled ferroelectric superconductivity and multiorbital effects in doped $SrTiO_3$

P24 **R. Kaneko** Dept. of Applied Physics, Univ. of Tokyo
Enhanced Thermopower in Hole-doped Pyrochlore Iridates with Quadratic Band Touching

P25 **R. Kaneko** ISSP, The Univ. of Tokyo
Assessing the numerical accuracy of tensor-network representation of the Kitaev spin liquid

P26 **M. Kawano** Basic Science, Univ. of Tokyo
Rashba-Dresselhaus effect in magnetic insulators

P27 **S. Kittaka** ISSP, Univ. of Tokyo
Field-orientation effect on the hidden-order transition in URu_2Si_2

P28 **A. Kobayashi** ISSP
Synthesis and magnetic transport properties of antiferromagnet Mn_3Ge, Mn_3Sn thin films

P29 **H. Kondo** Dept. of Physics, The Univ. of Tokyo
Z_2 topological invariant for magnon spin Hall systems

P30 **H. Masuda** Dept. of Applied Physics, The Univ. of Tokyo
Impact of antiferromagnetic order on Landau level splitting of quasi-two-dimensional Dirac fermions in $EuMnBi_2$

P31 **K. Matsubayashi** The Univ. of Electro-Communications
Pressure-tuning of the interplay between ferroquadrupole order and superconductivity in $PrTi_2Al_{20}$

P32 **T. Matsuda** ISSP, The Univ. of Tokyo
Terahertz anomalous Hall effect in Weyl antiferromagnet Mn_3Sn thin film

P33 **A. H. Mayo** Depart. of Applied Physics, The Univ. of Tokyo
Band-tuning-induced giant topological Hall effect in magnetic semimetal α-EuP_3

P34 **T. Chen** ISSP, The Univ. of Tokyo
Large Topological Responses in the Antiferromagnet Mn_3Ge

P35 **Y. Michishita** Kyoto Univ.
Non-hermitian properties in f-electron materials

P36 **T. Miyamachi** ISSP, The Univ. of Tokyo
Atomic-scale structural and electronic properties of YbB_{12}(001) surfaces

P37 **T. Mizoguchi** Dept. of Physics, Univ. of Tsukuba
Majorana edge magnetization in the Kitaev honeycomb model

P38 **M. Mogi** Dept. of Appl. Phys., The Univ. of Tokyo
Large anomalous Hall effect in topological insulators with proximitized ferromagnetic insulators

P39 **H. Nakamura** ISSP, The Univ. of Tokyo

Topologically Enhanced Anomalous Nernst Effect in Half-Heusler Ferromagnet CoMnSb

P40 **T. Nakamura** ISSP, The Univ. of Tokyo

In-plane field and current dependence of the Josephson effect in Nb/InAs/Nb junctions

P41 **J. Nasu** Dept. of Physics, Yokohama Natl. Univ.

Non-equilibrium dynamics by field quench in Kitaev model

P42 **R. Noguchi** ISSP, The Univ. of Tokyo

Quasi-1D bismuth halides exhibiting various topological phases investigated by ARPES

P43 **T. Ohtsuki** ISSP, The Univ. of Tokyo

Spontaneous Hall effect in a Luttinger semimetal Pr_2Ir2O_7 thin film

P44 **S. Okumura** Dept. of Applied Physics, The Univ. of Tokyo

Numerical study of nonreciprocal spin current in monoaxial chiral magnets

P45 **T. Omi** Dept. of Advanced Materials Science, The Univ. of Tokyo

Magnetic phase diagram of an orthorhombic Kagomé cobaltite $CaBaCo_4O_7$

P46 **M. Onizaki** ISSP, The Univ. of Tokyo

Supercurrent on accumulation edges of an InAs quantum well

P47 **S. Ono** ISSP, The Univ. of Tokyo

Symmetry indicators for topological superconductors

P48 **R. Peters** Kyoto Univ.

Quantum oscillations in topological Kondo insulator

P49 **J. Puebla** CEMS-RIKEN

Spin to charge conversion via magnon - phonon coupling

P50 **H. Saito** Spintronics Research Center

Spin-dependent diode performance in fully epitaxial magnetic tunnel junctions with rock-salt type ZnO/MgO bilayer tunnel barrier

P51 **A. Sakai** ISSP, The Univ. of Tokyo

Giant anomalous Nernst effect at room temperature in Co_2MnGa

P52 **N. Sakamoto** Dept. of Physics, Graduate School of Science, Kyoto Univ.

Chirality inversion and thermal Hall effect in Weyl superconducting state of URu_2Si_2

P53 **R. Sakano** ISSP, The Univ. of Tokyo
Spin current correlation in a three terminal quantum dot

P54 **S. Sakuragi** ISSP, The Univ. of Tokyo
Observation of magnetically combined two-dimensional electronic states in a layered antiferromagnet $EuSn_2As_2$

P55 **R. Sasaki** Basic Science, The Univ. of Tokyo
Surface acoustic wave on natural and artificial multiferroics.

P56 **T. Shimizu** ISSP, The Univ. of Tokyo
Control of electron spin through quantum Hall edge-spin entanglement

P57 **N. Sogabe** ISSP, The Univ. of Tokyo
Quadrupolar Kondo Effect in Magnetoresistance of Non-magnetic Γ_3 System PrV_2Al_{20}

P58 **D. Takagi** Dept. of App. Phys, Nagoya Univ.
Theory of proximity effect in Rashba nanowire junction

P59 **T. Takashiro** Dept. of Phys., Univ. of Tokyo
Fabrication and Evaluation of Magnetic Topological Insulator Heterostructure MnTe/ $(Bi_{1-x},Sb_x)_2Te_3$

P60 **H. Takeda** ISSP, The Univ. of Tokyo
Pressure induced phase transition on a frustrated square lattice spin system $RbMoOPO_4Cl$

P61 **K. Takubo** ISSP, The Univ. of Tokyo
Observation of collective phonon mode in quantum spin-orbital liquid $Ba_3CuSb_2O_9$ using time-resolved resonant x-ray scattering

P62 **K. Tanaka** Dept. of Basic Science, Univ. of Tokyo
Realization of spin nematic phases in antiferromagnetic dimer dumbbell models on two-dimensional lattices

P63 **N. Tang** ISSP, The Univ. of Tokyo
Metamagnetism, Criticality and Dynamics in the Quantum Spin Ice $Pr_2Zr_2O_7$

P64 **Y. Tomioka** AIST
Superconductivity near a ferroelectric quantum critical point in La-doped $SrTiO_3$

P65 **R. Toshio** Dept. of Physics, Kyoto Univ.
Applications of Electron Hydrodynamics to Nonlocal and Nonlinear Optical Effects

P66 **K. Ueda** Dept. of Applied Physics, The Univ. of Tokyo
Spontaneous Hall effect in all-in all-out Weyl semimetal of pyrochlore iridate

P67 **R. Yamada** Dept. of Applied Physics, The Univ. of Tokyo
Strong-correlation induced highly mobile electrons in Dirac semimetal of perovskite $CaIrO_3$

P68 **K. Yamamoto** Dept. of Physics, Kyoto Univ.
Fate of loss-induced superconductivity studied by non-Hermitian mean field theory

P69 **T. Yamamoto** ISSP, The Univ. of Tokyo
Quantum critical phenomena in heat transport in the subohmic spin-boson system

P70 **H. Yasuoka** Max Plank Institiute, CPfS
Local magnetic excitations in Weyl semi-metals explored by NMR and NQR spectroscopy.

P71 **T. Yokouchi** CEMS, RIKEN
Creation of skyrmions by surface acoustic waves

P72 **T. Yoshida** Univ. of Tsukuba
Symmetry-protection of exceptional points for correlated systems in equilibrium

P73 **Y. Zhang** ISSP, The Univ. of Tokyo
Investigation of Ir Magnetism in $LaMnO_3/SrIrO_3$ Superlattices by Hard X-ray Magnetic Circular Dichroism

P74 **Z. Zhu** ISSP, The Univ. of Tokyo
Comparison of Spin Hall Angles for Epitaxial and Polycrystalline Platinum Thin Films

Abstracts of Workshop

O18-1

Topological Transitions and Chiral Majorana Fermion

Kang L. Wang

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Energy dissipation has become the major challenge for today's electronics and computer. Recent advances of physics incorporating topology with spintronics have revealed new physics and at the same time made possible many device possibilities. Topological transitions have also been used to demonstrate dissipation-less quantum anomalous Hall in magnetic doped topological insulator and to control spin texture. In particular, topological material heterostructures composed of, e.g., TI and antiferromagnets (AFM) or superconductors are shown to offer interesting new physics. In this talk, some of these physics and potentials will be discussed. Specifically, AFM/TI heterostructures are shown to give rise to a marked increase in magnetic orders, e.g., exchange coupling with three times of enhancement in the Curie temperature of a magnetic doped TI. These topological transitions at the interfaces of the TI/AFM heterostructure can be controlled by applying a small magnetic field. The edge state of the quantum anomalous Hall using a magnetic doped topological insulator has been demonstrated to have millimeter coherent transport lengths. For the heterostructure consisting of a QAH edge state interfaced with a superconductor, new phase topological phase transitions can also occur and a topological superconductor phase is predicted. For such heterostructure, by reducing three dimensional systems to two dimensions at the interface, chiral Majorana can be hosted. Majorana was proposed in 1937 by Ettore Majorana as a particle being its antiparticle. Since its inception, Majorana has been under intensive pursuit both theoretically and in experiments. In the heterostructure consisting of a QAH insulator and a superconductor, our recent experimental results showed a half-integer and a two-integer of quantized conduction plateaus (0.5 e^2/h and 2 e^2/h), which give firm signatures of the elusive Majorana fermion for the first time in 80 years. A recent report of different systems using an InSb nanowire interfaced with a superconductor confirmed a similar two-quantized plateau. The contrast of ours results with the more recent confirmation using the InSb nanowire with a superconductor mentioned above will also be discussed [2]. Using Majorana particles as topological qubits, topological quantum computer may be realized. The findings offer a new direction for robust topological quantum computing to mitigate the de-coherence challenge. Our finding offers a potential for constructing robust topological quantum computing to mitigate the challenge of decoherence of today's approaches in quantum computer.

[1]. Qinglin He, .. Kang L Wang, Science, V.357, Issue 6348, pp. 294-299 (21 July, 2017);
[2]. Hao Zhang, … Leo Kouvenhoven, Nature V.556, pages 74–79 (05 April 2018)

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O18-2

Emergent magneto-transport phenomena in strongly correlated topological phase

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Berry curvature arising from the Weyl fermions and/or the real-space scalar spin chirality can give rise to the action of effective magnetic field on the conduction electrons and hence produce the topological Hall effect. Furthermore, their temporal dynamics can also cause versatile emergent phenomena, including nonreciprocal transport, enhanced carrier scattering, thermoelectric effect, etc. Here, taking the examples of cubic chiral magnets, frustrated triangular- or Kagome-lattice magnets and magnetic topological insulators, we report the experimental attempts to design and maximize the emergent magnetic-field effects with possible applications to spintronic functions.

[1] A. Author, B. Second and C. Third, Phys. Rev. B **100**, 012345 (2019).

[2] http://tpfc.issp.u-tokyo.ac.jp/registration.htm

O18-3

Topological Nature and Anomalous Nernst effect in Magnetic Weyl Metals

T. Tomita[1], T. Chen[1], M. Ikhlas[1], T. Koretsune[2], R. Arita[3], and S. Nakatsuji[1]
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[2]*Department of Physics, The University of Tokyo, Japan.*
[3]*Department of Physics, Tohoku University, Japan.*

Antiferromagnets Mn_3X (X = Sn, Ge) are found to exhibit a large anomalous Hall effect, even at room temperature and far above, although having vanishingly small magnetization [1,2]. Usually, this anomalous Hall effect is known to be proportional to magnetization and thus has been observed only in ferromagnets. The spontaneous Hall resistivity indicates that the large fictitious field equivalent to a few hundred T must exist in the momentum space. Recent DFT calculation predicts that the large fictitious field may well come from a significantly enhanced Berry curvature associated with the formation of Weyl points nearby the Fermi energy E_F [3]. Recent theoretical study of magnetic space group have also clarified the ferroic-order of magnetic octupoles in chiral non-collinear Mn_3X is sufficient to induce a non-zero net Berry curvature [4].

Here, we report a striking discovery of a large spontaneous Nernst effect of ~ 0.35 μV/K in Mn_3Sn at room temperature and ~ 0.6 μV/K at low temperatures. The Nernst signals are found more than 100 times larger than what would be expected based on the magnetization [5]. Besides, we found strong experimental evidence of the Weyl fermions in Mn_3Sn, namely, that the band structure is found consistent with DFT by ARPES and the chiral anomaly is clarified in the magnetotransport measurements. Thus, our experiments demonstrate that the large anomalous Hall and Nernst signals arise from the Berry curvature associated with the Weyl points near the E_F [6]. In our talk, we also inform the anomalous Nernst effect of Mn_3Ge and discuss the topological nature of Weyl magnets by comparing Mn_3Ge with Mn_3Sn.

[1] S. Nakatsuji, N. Kiyohara, and T. Higo, Nature **527**, 212-215 (2015).
[2] N. Kiyohara, T. Tomita, and S. Nakatsuji, Phys. Rev. Applied **5**, 064009 (2016).
[3] H. Yang, Y. Sun, Y. Zhang, W-J. Shi, S. S. P. Parkin, and B. Yan, New J. Phys. **19**, 015008 (2017).
[4] M.-T. Suzuki, T. Koretsune, M. Ochi, and R. Arita Phys. Rev. B **95**, 094406 (2018).
[5] M. Ikhlas, T. Tomita, T. Koretsune, M. –T. Suzuki, D. Nishio-Hamane, R. Arita, Y. Otani, and S. Nakatsuji. Nature Physics **13**, 1085-1090 (2017).
[6] K. Kuroda, T. Tomita, M.-T. Suzuki, C. Bareille, A. A. Nugroho, P. Goswami, M. Ochi, M. Ikhlas, M. Nakayama, S. Akebi, R. Noguchi, R. Ishii, N. Inami, K. Ono, H. Kumigashira, A. Varykhalov, T. Muro, T. Koretsune, R. Arita, S. Shin, T. Kondo, and S. Nakatsuji, Nature Materials **16**, 1090-1095 (2017).

O18-4

Discovery of weak topological insulator state in quasi-one-dimensional bismuth iodide

Takeshi Kondo

Institute for Solid State Physics, The University of Tokyo, Japan

The major breakthroughs in the understanding of topological materials over the past decade were all triggered by the discovery of the Z_2 topological insulator (TI). In three dimensions (3D), the TI is classified as either "strong" or "weak", and experimental confirmations of the strong topological insulator (STI) rapidly followed the theoretical predictions. In contrast, the weak topological insulator has so far eluded experimental verification, since the topological surface states emerge only on particular side surfaces which are typically undetectable in real 3D crystals. In my talk, I will provide experimental evidence for the weak topological insulator (WTI) state in a bismuth iodide, β-Bi_4I_4. Significantly, the crystal has naturally cleavable top and side planes both stacked via van-der-Waals forces, which have long been desirable for the experimental realization of the WTI state. As a definitive signature of it, we find quasi-1D Dirac topological surface state (TSS) at the side-surface (100) while the top-surface (001) is topologically dark (Fig.1). Furthermore, a crystal transition from the β- to α-phase drives a topological phase transition from a nontrivial WTI to the trivial insulator around room temperature. The weak topological phase, viewed as quantum spin Hall (QSH) insulators stacked three-dimensionally will lay a foundation for new technology benefiting from highly directional spin-currents with large density protected against backscattering [1].

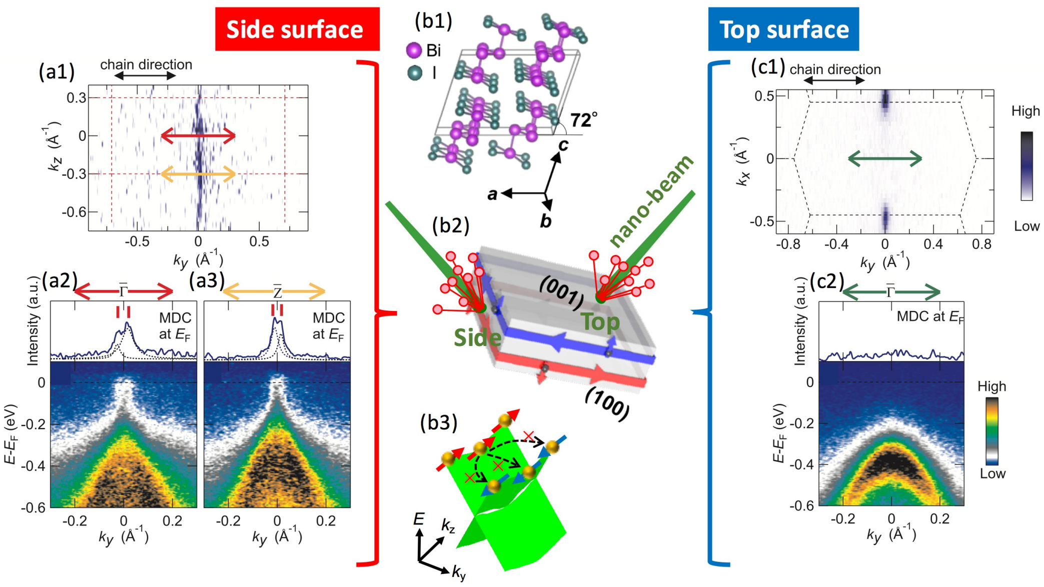

Fig. 1: ARPES results for the side surface (left panels) and the top surface (right panles) obtained by nano-ARPES. (a1-a3) Fermi surface mapping, and band dispersions for the side surface. (b1) Crystal structure of β-Bi_4I_4. (b2) Schematic of measurements with nano-ARPES. (b3) Spin-polarized band structure with quasi one dimntion for the side surface. (c1,c2) Same data as (a1-a3), but for the top surface.

[1] R. Noguchi *et al*., *Nature* (2018), in press.

O18-5

Dynamics and transport in quantum magnets

L. Balents[1],
[1]*Kavli Institute of Theoretical Physics, University of California, Santa Barbara, CA*

I will discuss aspects of dynamics and transport in quantum magnets. To be determined.

O18-6

Proton-dynamics Coupled Quantum Spin Liquid State and Magnetic Switching in Organic Mott System

H. Mori[1]

[1]*Institute for Solid State Physics, The University of Tokyo, Japan*

Novel quantum phases and quatum transport is the central issue in the field of quantum condensed matter physics and materials sciences. Quantum phenomena are generally observed as behaviors of electrons by using charge, spin, lattice, and orbitals degrees of freedom. Moreover, hydrogen as well as electron possesses quantumness due to the lightest atom and affords a variety of states by coupling of an electron and a proton: H (hydrogen atom), H_2 molecule (covaleted hydrogen molecule), H^+ (proton), H^- (hydride), etc.

Recently, we have explored novel phenomena and functionalies with coupling of electron and proton [1-5]. As a result, (1) metallic state of purely organic conductor based upon protonated single units under 1 GPa for κ-H_3(Cat-EDT-ST)$_2$, [2] , (2) quatum spin liquid state with coupling of quantum fluctuaion of proton for κ-H_3(Cat-EDT-TTF)$_2$ [2,3,5], and (3) magnetism and conductivity switching as large deuterium isotope effect with ΔT_c = 185 K for κ-D_3(Cat-EDT-TTF)$_2$ [4] have been discovered.

This research has been carried out by the collaboration with Mr. T. Takakura, Drs. A. Ueda J. Yoshida, M. Shimozawa, M. Yamashita, J. Gouchi, Y. Uwatoko (ISSP), A. Nakao (CROSS), K. Kobayashi, R. Kumai, H. Nakao, Y. Murakami (KEK-PF), K. Takahashi (Kobe Univ.), T. Isono, S. Uji (NIMS), and K. Yamamoto (Okayama Sci. Univ.)

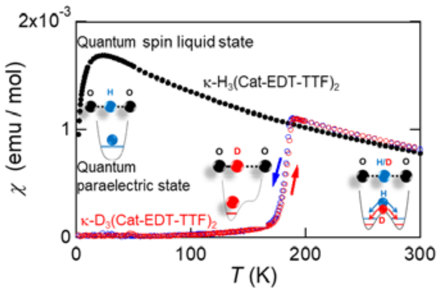

Figure 1: Quantum spin liquid state, and magnetism and conductivity switching in organic proton-electoron coupled systems, κ-X_3(Cat-EDT-TTF)$_2$ [X = H, D].

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O18-7

The quantum dipole liquid in triangular lattice molecular Mott insulators and its relevance to a spin liquid

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Mott insulators are commonly pictured with electrons localized on lattice sites with their low-energy physics involving spins only. Using Raman spectroscopy as the main tool, we have demonstrated the presence of on-site electric dipoles in some molecule-based Mott insulators on a triangular lattice [1]. In k-(BEDT-TTF)$_2$Hg(SCN)$_2$Br, when electrons localize on a triangular lattice of molecular dimers at temperatures below 100 K, they form electric dipoles which do not order at low temperatures and fluctuate, resulting in a so-called quantum dipole liquid state. A collective mode of dipole fluctuations is observed in Raman spectra at 1.3 THz. In the sister compound k-(BEDT-TTF)$_2$Hg(SCN)$_2$Cl, on-site electric dipoles order below 30 K, however we demonstrate that at lower temperatures this charge order melts. According to our recent results, this material shows paramagnetic behavior down to low temperatures suggestive of a spin liquid state.

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O18-8

Theory of proton-driven quantum spin-dipole liquid

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Motivated by the recent discovery of coexistence of unfrozen spin and electric-dipole fluctuations in the organic dimer Mott insulator κ-H_3(Cat-EDT-TTF)$_2$ called H-Cat [1], we present a theory of a new quantum liquid state based on a model of hydrogen-bonded systems where electrons are coupled with quantum proton motion. There are macroscopically degenerate ground states in the classical limit, and quantum fluctuations of the proton motion will lift the degeneracy. The resulting quantum ground state can be regarded as a variant of the U(1) spin liquid in three spatial dimensions. We also discuss implications for the experiments in H-Cat and its deuterated analog D-Cat.

[1] M. Shimozawa *et al.*, Nat. Commun., **8**, 1821 (2017).

O18-9

Voltage control of magnetic anisotropy and its application to voltage-torque MRAM

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Voltage control of spin enables both a zero standby power and ultralow active power consumption in spintronic devices such as magnetoresistive random-access memory MRAM. A practical approach to achieve voltage control is the electrical modulation of the spin–orbit interaction at the interface between 3d-transition-ferromagnetic-metal and dielectric layers in a magnetic tunnel junction (MTJ). However, we need to initiate a new guideline for materials design to improve both the voltage-controlled magnetic anisotropy (VCMA) and perpendicular magnetic anisotropy (PMA). We report that atomic-scale doping of iridium in an ultrathin Fe layer is highly effective to improving these properties in Fe/MgO-based MTJs. Iridium doping yielded both a large enhancement of PMA and a huge VCMA coefficient (up to 320 fJ/Vm) with high-speed response [1,2]. First-principles calculations revealed that Ir atoms dispersed within the Fe layer play a considerable role in enhancing PMA and the VCMA coefficient. These results demonstrate the efficacy of heavy-metal doping in ferromagnetic layers as an advanced approach to develop high-density voltage-driven spintronic devices. We also report on experimental evaluation of write error rate (WER) of voltage-induced dynamical switching and its theoretical analyses based on macro-spin model [3-4]. We show a good agreement between experimental results and theory. This work was supported by the ImPACT Program of the Council for Science, Technology and Innovation.

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O18-10

Electric-field-induced change of perpendicular magnetic anisotropy at metal/dielectric interface

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[2]*Center for Spintronics Research Network, Osaka University, Japan*

Electric-field-induced control of magnetic properties at room temperature has attracted considerable attention owing to its significant potential for facilitating the construction of ultralow-power-consumption electric devices. Voltage-controlled magnetic anisotropy (VCMA) in ferromagnetic metallic multilayered structure [1,2] has shown that magnetization can be controlled in fast periods (down to 0.1 ns) by electric fields, as indicated by bi-stable precessional magnetization switching, and ferromagnetic resonance excitation. Because the VCMA mechanism can be purely electronic, this is an ultimate technology for the operation of spintronics devices, such as nonvolatile random access memory, where high-speed operation with high writing endurance is indispensable.

In this talk, we will show a microscopic origin of the VCMA effect [3-5]. Firstly, VCMA effect in 3*d*-transition metals can be explained by electric-field-induced change of orbital magnetic moment, that is, charge doping effect. We show it in terms of X-ray magnetic circular dichroism (XMCD) spectroscopy of Co-absorption edge on Fe-Co-MgO multilayer [3]. Secondly, VCMA effect in 5*d*-transition metals can be explained by both electric-field-induced changes of orbital magnetic moment and magnetic dipole T_z term, that is, charge redistribution effect. We show it in terms of XMCD spectroscopy of Pt-absorption edge on Fe-Pt-MgO multilayer. Specifically, the magnetic dipole T_z induction is correlated to an electric quadrupole induction in interfacial metallic atoms with MgO tunnel barrier, and it changes the perpendicular magnetic anisotropy energy through spin-flip virtual excitation process. Such an electric quadrupole induction can be feasible due to nonlinear electric field potential because of the strong electrostatic screening effect in metals [5].

This work is a collaboration work with Y. Suzuki, F. Bonell, K. Matsuda, T. Tsukahara, T. Kawabe, J. Suwardy, K. Nawaoka, M. Goto, and E. Tamura of Osaka University, M. Suzuki, Y. Kotani, K. Toyoki, and T. Nakamura of JASRI, T. Nozaki, and S. Yuasa of AIST, M. Tsujikawa, and M. Shirai of Tohoku University, T. Ohkubo, and K. Hono of NIMS.

[1] M. Weisheit *et al.*, Science **315**, 349 (2007)
[2] T. Maruyama *et al.*, Nat. Nanotechnol. **4**, 158 (2009)
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O18-11

Ultrafast demagnetization in Pt-containing ferromagnetic thin films probed by x-ray free electron laser

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In recent times, photo-induced magnetism has attracted significant attention from researchers because of its non-trivial mechanism and avenues for practical application. Considering this, to understand the mechanism of photo-induced magnetization dynamics, element-specific measurements are necessary because magnetic materials that show remarkable photo-induced behaviors contain more than one magnetic element. X-ray free electron laser is useful for this purpose because of its ultrashort pulses and tenability of photon energy and we can perform time-resolved element-specific magnetic dynamics measurement by core level absorption.

We demonstrate ultrafast magnetization dynamics in a 5d transition metal using circularly-polarized x-ray free electron laser in the hard x-ray region[1]. A decay time of light-induced demagnetization of $L1_0$-FePt was determined to be τ_{Pt} = 0.6 ps using time-resolved x-ray magnetic circular dichroism at the Pt L_3 edge as shown in Fig. 1, whereas magneto-optical Kerr measurements indicated the decay time for total magnetization as τ_{total} = 0.1 ps. A transient magnetic state with the photo-modulated magnetic coupling between the 3d and 5d elements is firstly demonstrated. We also carried out time-resolved resonant magneto optical Kerr effect measurement for ferromagnetic multilayer thin film and obtained consistent results.

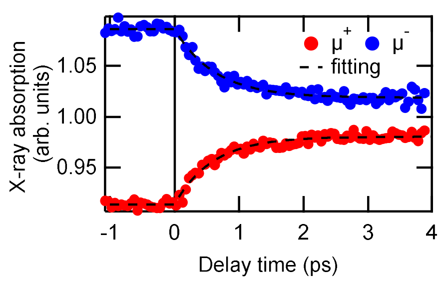

Figure 1: Time-resolved x-ray magnetic circular dichroism of FePt at Pt L edge.

[1] K. Yamamoto *et al.*, arXiv:1810.02551.

O19-1

Magic Angle Twisted Bilayer Graphene

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Magic Angle Twisted Bilayer Graphene (MATBG) is a remarkably tunable and relatively simple strongly correlated electron system, with its own set of specific peculiarities. My talk will focus on similarities and differences between the interaction physics of flat-band moiré superlattices in transition metal dichalcogenide bilayers, which are well described by single-band Hubbard models, and the corresponding interaction physics in MATBG systems, which are not. I will discuss the nature of the insulating ground states and the collective excitation spectra at 1/2, 1/4, and 3/4 filling of the moiré conduction and valence bands, address the issue of finding the optimal compromise between simplicity and accuracy in the construction of models suitable for analysis in the strong coupling limit, and speculate on the relationship between the insulating states and their collective models and the superconducting domes.

O19-2

Anomalous transverse transport and domain wall motion in non-collinear antiferromagnets

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Recently, Mn_3Sn has attracted considerable attention as a magnetic Weyl semimetal [1] exhibiting a large anomalous Hall effect [2,3,4] and anomalous Nernst effect [5,6]. While these effects are usually observed in ferromagnets, the net (uniform) magnetization is vanishing small in the non-collinear antiferromagnetic structure of Mn_3Sn. Interestingly, this magnetic structure can be viewed as ferroic ordering of cluster magnetic octupoles. In fact, this octupole can induce anomalous transverse transport, since its irreducible representation is the same as that of the magnetization (magnetic dipole) [7]. More recently, Higo *et al.* have observed a large magneto-optical Kerr effect in Mn_3Sn, and succeeded in visualizing magnetic octupole domains and their reversal [8].

Motivated by this experiment, we perform numerical simulations with the atomistic Landau-Lifshitz-Gilbert (LLG) equation and investigate the dynamics of a domain wall in Mn_3Sn. We show that the spin-orbit torque drives the domain wall much faster than that in ferromagnets. Next, we rewrite the LLG equation in terms of cluster multipoles and derive an equation of motion for the magnetic octupole, which can be solved analytically. The analytical solution reproduces the numerical simulation very accurately. This result indicates that the cluster magnetic octupole is a useful order parameter to describe the domain wall motion and spin dynamics in non-collinear antiferromagnets.

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O19-3

Crystal symmetries and transport phenomena in antiferromagnets

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The suppression of dipolar fields in antiferromagnets is favorable for high density integration of memory elements and makes them robust against magnetic field perturbations. Other unique merits of antiferromagnetic spintronics include the multi-level switching, suitable for integrating memory with logic or neuromorphic functionalities, and the ultra-fast THz spin dynamics. In the lecture we will first give a brief overview of the multiple directions in current research of antiferromagnetic spintronics [1]. We will then outline the rich symmetry and topology landscape of antiferromagnets which allows for a range of transport phenomena suitable for manipulating and detecting antiferromagnetic spins. Our main focus will be on electrical readout of 180^o spin-reversal in collinear antiferromagnets [2]. Apart from microscopic imaging of a domain wall motion, this can be facilitated by a second-order magnetoresistance effect in antiferromagnets with broken time and space-inversion symmetries. In the linear response, the magnetic structure alone cannot generate a spontaneous Hall effect collinear antiferromagnets. However, we introduce a mechanism and corresponding candidate collinear antiferromagnets, in which the breaking of time-reversal and other symmetries required by the Hall effect is caused by the arrangement of non-magnetic atoms in the lattice. Hall conductivities as large as 1000 S/cm are obtained in our first-principles calculations which originate from spin-orbit coupled bands with topological signatures linked to the remaining crystal symmetries in the considered collinear antiferromagnets.

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O19-4

Large time-reversal-odd responses in the Weyl antiferromagnet Mn_3Sn bulk and thin film for antiferromagnetic spintronics

T. Higo[1,2], H. Man[1], M. Ikhlas[1], D. Qu[1], D.B. Gopman[3], Y.P. Kabanov[3], O.M.J. van ’t Erve[4], Liang Wu[5,6], D. Rees[6], S. Patankar[6], Yufan Li[7], T. Koretsune[8], M.-T. Suzuki[8], R.D. Shull[3], J. Orenstein[6], C.L. Chien[7], R. Arita[9,10], Y. Otani[1,2,9] and S. Nakatsuji[1,2,7]

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In the last few years, there has been a surge of interest in antiferromagnetic (AF) materials due to their favorable properties including vanishingly small stray field, faster spin dynamics, and abundance in nature compared to their FM counterparts [1]. In fact, motivated by these intriguing properties, several breakthroughs have been made; for example, the anisotropic magnetoresistance (AMR), even-function response under time-reversal (TR), has been found useful for detecting the collinear AF ordering [2]. Another breakthrough is the discovery of odd-function response under TR in Mn_3Sn such as anomalous Hall [3] and Nernst [4] effects, magneto-optical Kerr effect (MOKE) [5] and a novel type of (magnetic) spin Hall effect [6] at zero magnetic field. Moreover, experimental studies have shown that Mn_3Sn is the first version of a Weyl magnet where the Weyl fermions near the Fermi energy give rise to the TR-odd topological responses [7]. In this talk, we will propose the Weyl antiferromagnet Mn_3Sn as a promising material for the AF spintronics. This is because Mn_3Sn exhibits the large TR-odd responses such as the anomalous Hall effect at zero magnetic field [3], and these spontaneous responses can be controled by the AF domain with ferroic ordering of the magnetic octopole which has been observed by the MOKE [5]. We will also show that not only the bulk crystals but also Mn_3Sn thin films exhibit large TR-odd responses [8], which provides an important step for further developing spintronics devices using AF materials.

[3]*NIST, USA.* [4]*US Naval Research Laboratory, USA.* [5]*University of California, Berkeley, USA.* [6]*University of Pennsylvania, USA.* [7]*Johns Hopkins University, USA.* [8]*Tohoku University, Japan.* [9]*RIKEN-CEMS, Japan.* [10]*University of Tokyo, Japan.*

[1] T. Jungwirth *et al*., Nat. Nanotech. **5**, 231 (2016).
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[3] S. Nakatsuji, N. Kiyohara, and T. Higo, Nature **527**, 212 (2015).
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[5] T. Higo *et al*., Nat. Photon. **12**, 73 (2018).
[6] M. Kimata *et al*., Nature (in press).
[7] K. Kuroda, T. Tomita *et al*., Nat. Mater. **16**, 1090 (2017).
[8] T. Higo *et al*., Appl. Phys. Lett. **113**, 202402 (2018).

O19-5

Observation of magnetic spin Hall effect and magnetic inverse spin Hall effect in a chiral antiferromagnet Mn_3Sn

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Spin Hall effect provides the spin-charge interconversion in non-magnetic materials, which has drawn much attention because of its potential application for efficient magnetization switching via the spin-transfer torque [1].

Here we focus on the non-collinear antiferromagnet Mn_3Sn to realize the new functionality in spin-charge conversion. M_3Sn exhibits the large anomalous Hall effect comparable with ferromagnet at room temperature [2]. Figure 1 shows a devise structure for spin accumulation detection. By applying the charge current on a Mn_3Sn strip, spin accumulation can be detected electrically by the ferromagnetic electrode. This technique enables us to observe the SHE in Mn_3Sn, exhibiting an anomalous sign change when its small magnetic moment switches orientation. Additionally, we succeeded in observation of the sign change in the inverse effect by means of spin pumping method. By comparison with theoretical toy-model, we found that such unique functionality in Mn_3Sn is caused by the momentum-dependent spin splitting produced by non-collinear magnetic order [3].

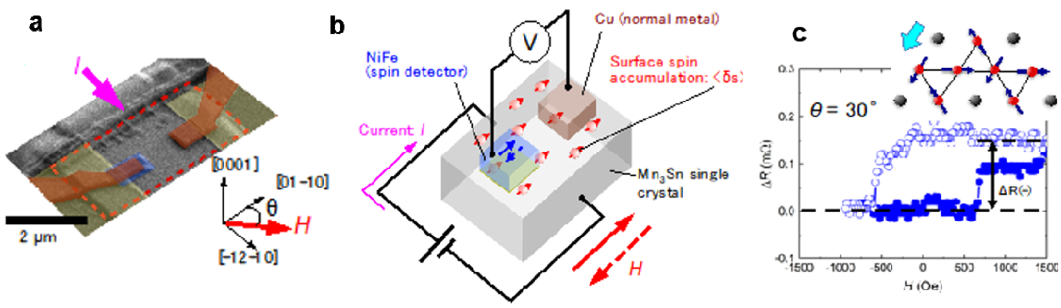

Figure 1 Device structure for spin accumulation detection a, SEM image of spin accumulation device **b,** Measurement setup. The electrical current was applied along [-12-10] direction. The external magnetic field was rotated within the device basal plane and the field angle θ was measured from the [01-10] axis. **c**, Spin accumulation signals. Magnetic field dependence of the resistance measured between NiFe-Cu electrodes at room temperature.

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O19-6

Majorana fermions and half-integer thermal quantum Hall effect in a quantum spin liquid

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The quantum Hall effect (QHE) is one of the most remarkable phenomena in contemporary condensed matter physics, which rivals superconductivity in its fundamental significance as a manifestation of quantum mechanics on a macroscopic scale. The quantum Hall state is a topological property of quantum matter. There are two classes of the QHE, where integer and fractional electrical conductance are measured in units of e^2/h. Here we report a novel type of quantization of the Hall effect caused by charge neutral quasiparticles, i.e. Majorana fermions, in an insulating two-dimensional (2D) quantum magnet, α-$RuCl_3$ with honeycomb lattice[1][2]. This material has been suggested to be a candidate of Kitaev quantum spin liquid (QSL), where significant entanglement of quantum spins is expected. In the low-temperature regime of the QSL state, the 2D thermal Hall conductance reaches a quantum plateau as a function of applied magnetic field. Surprisingly, the plateau attains a quantization value $\kappa_{xy}/T=1/2(\pi^2 k_B^2/3h)$, which is exactly half of that in the integer QHE. This half-integer thermal Hall conductance observed in a bulk material is a direct signature of topologically protected chiral edge currents of emergent Majorana fermions, whose degrees of freedom are half of those of electrons, and non-Abelian anyons in the bulk.

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O19-7

Spin Thermal Hall Conductivity of a Kagomé Antiferromagnet

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Searching for the ground state of a kagomé Heisenberg antiferromagnet (KHA) has been one of the central issues of condensed-matter physics, because the KHA is expected to host spin-liquid phases with exotic elementary excitations.

To study the elementary excitations, we investigate the longitudinal (κ_{xx}) and transverse (κ_{xy}) thermal conductivities of a new candidate of $S = 1/2$ KHA Ca kapellasite ($CaCu_3(OH)_6Cl_2 \cdot 0.6H_2O$) [1]. We find a clear thermal Hall signal in the spin liquid phase of $T^* < T < J/k_B$, where $T^* \sim 7$ K is the magnetic transition temperature and $J/k_B \sim 66$ K is the effective spin interaction energy [2]. The temperature dependence of κ_{xy}/T shows an increase as lowering temperature below J/k_B, which is followed by a peak at $T \sim J/3k_B$. We find that κ_{xy} is well reproduced, both qualitatively and quantitatively, by the Schwinger-boson mean-field theory [3] with the Dzyaloshinskii-Moriya interaction of $D/J = 0.1 - 0.3$. Most remarkably, both κ_{xy} of Ca kapellasite and that of another kagomé antiferromagnet volborthite [4] are found to converge to one single curve of our Schwinger-boson calculation only by choosing J and D as fitting parameters. This excellent agreement demonstrates not only that the thermal Hall effect in these kagomé antiferromagnets is caused by spins in the spin liquid phase, but also that κ_{xy} is given by a simple scaling function $f(k_B T/J)$, unveiling the spin $\kappa_{xy}(T)$ of KHA.

We further find that κ_{xy} of another kagomé compound, Cd kapellasite [5], can also be well reproduced by the same scaling function with smaller J. This is consistent with that J of Cd kapellasite is estimated as smaller than that of Ca kapellasite, demonstrating the validity of our scaling.

This work has been done in collaboration with M. Akazawa, H. Doki, Jung Hoon Han, Z. Hiroi, N. Kawashima, Hyun-Yong Lee, M. Oda, R. Okuma, M. Shimozawa, K. Sugii, and H. Yoshida.

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O19-8

Gapless spin liquid in the anisotropic triangular lattice antiferromagnet $A_3ReO_5Cl_2$ (A = Ca, Sr, Ba)

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The anisotropic triangular lattice (ATL) provides us with a unique playground for studying spin liquids existing between one and two dimensions. Anisotropy of the magnetic interaction on the triangular lattice is expected to lead to a variety of quantum phases including spiral order, gapless and gapped spin liquid phases [1, 2]. However, the number of model compounds is limited.

We report here new 5*d* quantum antiferromagnets $A_3ReO_5Cl_2$ (A = Ca, Sr, and Ba) [3], where Re^{6+} ions carrying Heisenberg spin-1/2 form an ATL (Fig. 1a). Each of these compounds shows a broad peak in the temperature dependences of magnetic susceptibility (Fig. 1b), which is nicely fitted by the Heisenberg spin-1/2 ATL model. In spite of the substantial two-dimensionality, one-dimensionality is clearly observed in the heat capacity data: a *T*-linear heat capacity with a consistent magnitude of the coefficient indicative of a gapless spin excitation is observed at low temperatures. This reduction of dimensionality from ATL to decoupled spin chains must be caused by geometrical frustration. This family of compounds can be a good model system to study the Heisenberg spin-1/2 ATL in a systematic way.

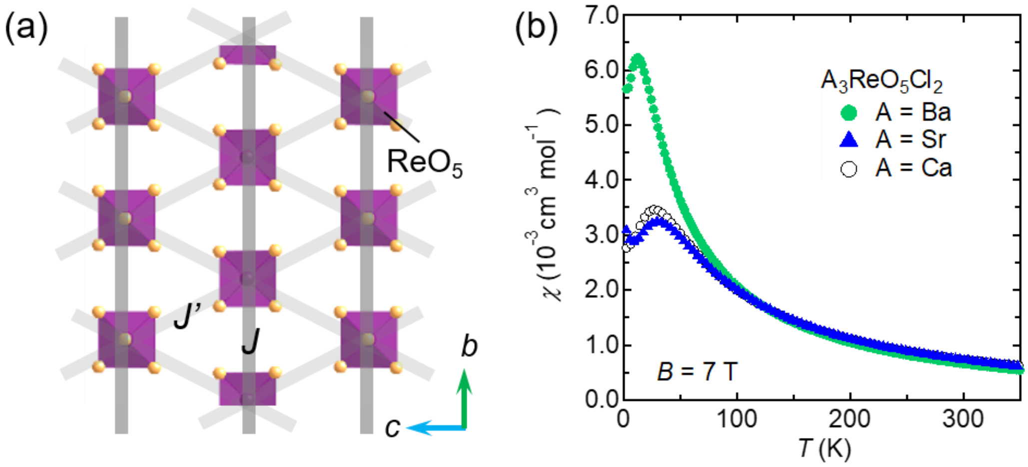

Figure 1: (a) Anisotropic triangular lattice fromed by Re^{6+} (S = 1/2) ions in $A_3ReO_5Cl_2$ (A = Ca, Sr, and Ba). (b) Temperature dependence of magnetic susceptibility of $A_3ReO_5Cl_2$.

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O20-1

Nonreciprocal transport in quantum materials

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When the system lacks both parity and mirror symmetries, it is called "chiral" and can be classified into right-handed and left-handed. Chirality is one of the most fundamental issue in many branches of sciences [1]. In physics, especially the dynamics of chiral matters is an important issue. In this talk, I will discuss that the most fundamental principles in physics manifest themselves in the nonreciprocal transport phenomea in chiral systems, i.e., the symmetries, dissipation, quantum-classical crossover/transition, quantal Berry phase and topology, and many-body correlation effects [2]. The concrete examples to discuss include magnetochiral anisotropy of semiconductors [3], Weyl semimetals [4], and superconductors [5], nonlinear spin current generation in Rashba-Dresselhaus systems, and shift currents under photo-excitations [6].

The collaborators of these works are T. Morimoto, K.W. Kim, R. Wakatsuki, K. Hamamoto, M. Ezawa, H. Ishizuka, S. Hoshino, S.Koshikawa, S.Shimizu, Y.Kaneko Y. Saito, T. Ideue, Y. Iwasa, and Y. Tokura.

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O20-2

Skyrmion lattice in f-electron magnet EuPtSi

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The lack of spatial inversion symmetry in a structure results in appearance of antisymmetric interactions, that may induce unconventional states of matter. In cubic $B20$-type compounds crystallizing in the space group $P2_13$, as represented by MnSi, a combination of the Dzyaloshinsky−Moriya and ferromagnetic interactions results in a helimagnetic structure with long pitch. An application of a magnetic field in MnSi induces a field-induced ordered state with magnetic skyrmions, particle-like topologically non-trivial spin textures, as evidenced by small-angle neutron scattering[1]. Following this discovery, intensive search on skyrmions has conducted for materials particularly in this space group, that leads to find new class of materials, such as FeGe[2], Cu_2OSeO_3[3]. Whereas diverse properties of skyrmions have been revealed so far, materials hosting the skyrmion lattice were mostly limited to $3d$-electron systems.

Rare-earth intermetallic compound EuPtSi also crystallizes in the cubic space group $P2_13$. Recent study revealed that an application of magnetic fields induces a transition from an antiferromagnetic ground state to a field-induced ordered phase, called A phase, in the intermediate temperature range[4], that reminds us the skyrmion phase in MnSi. In addition, emergence of additional Hall resistivity was confirmed when the system enters into the A phase. A complementary use of neutron diffraction, small-angle neutron scattering, and resonant X-ray scattering gives further microscopic evidence for the formation of the skyrmion lattice in EuPtSi[5, 6]. In contrast to similarities in the phase diagram and transport, there exists clear differences with $3d$ systems, such as periodicity and anisotropy. This discovery in $4f$ electron compound will extend to other f-electron systems, and help to deepen our understanding on skyrimion physics.

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O20-3

Magnetization of the skyrmion lattice phase and field-induced tricritical point in EuPtSi

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EuPtSi crystallizes in a cubic chiral structure with the space group $P2_13$, the same as MnSi. This compound helimagnetically orders at T_N=4.1 K [1, 2]. We examined the magnetic phase transitions of EuPtSi by means of high-precision magnetization measurements on a high-quality single crystal, and established the phase diagrams.

The helimagnetic order at T_N is known to be weakly first order [1, 2]. This is a fluctuation-induced first-order transition (FOT) [2], which is driven by the interactions between critical fluctuations of the order parameters when the degrees of freedom of the OP is large. By increasing the magnetic field, we observed that FOT turns into a second-order transition above a field-induced tricritical point (TCP). The location of TCP strongly depends on the field direction.

This compound exhibits an exotic magnetic phase (A-phase) in the intermediate field range within the conical state below T_N [3, 4]. Very interestingly, additional Hall resistivity has recently been observed in this field-induced phase [3], bearing a close resemblance to the skyrmion lattice phase in MnSi. The possibility of the skyrmion lattice phase in EuPtSi has further been supported by the recent neutron diffraction measurements [4]. Our magnetization data for $H \parallel [100]$ and [111] clearly indicate that the A-phase is entered from the conical phase accompanied by a sharp peak in dM/dH; the phase transition is of first order. The A-phase is stabilized only at finite temperatures above 0.3 K, depending crucially on the field direction; no A-phase appears for H near [110] direction. In the ground state below 0.3 K, the A-phase is absent in thermal equilibrium and the magnetization of the conical state linearly increases with H and saturates near 3 T for all directions. The magnetic anisotropy of the system is therefore weak as expected for the $L = 0$ ground state of Eu^{2+} ions, although the phase diagram is highly anisotropic.

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O20-4

Theory of Multipolar Order and Multipolar Kondo Effect

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Motivated by a series of recent experiments on the cubic heavy fermion systems such as $PrTi_2Al_{20}$ and PrV_2Al_{20}, we develop a general Landau theory of multipolar order. Here the non-Kramers local moments at Pr sites carry the quadrupolar and octupolar moments, and interact with conduction electrons. We show how such a theory can be used to predict the generic phase diagram and discuss experimental signatures of the multipolar order. In particular, we explain how the magnetostriction can be used to detect the multipolar order parameters. The "Kondo"-like effect due to the coupling between the multipolar moments and conduction electrons will also be discussed.

O20-5

Field-induced switching of ferro-quadrupole order parameters in $PrTi_2Al_{20}$

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We report a magnetic-field-induced first order phase transition in the ferro-quadrupole ordered state of $PrTi_2Al_{20}$, in which non-Kramers Pr^{3+} ions with two 4*f* electrons have the non-magnetic Γ_3 doublet ground state in the cubic (*T*d) crystalline electric field. For the magnetic field along [111], the ^{27}Al-NMR and magnetization experiments revealed that $Qz \sim 3z^2 - r^2$ type ferro-quadrupole order develops below 2 K independent of magnitude of the field. When the field is applied along [001] or [110], however, a discontinuous transition is induced by a small field of 1 - 2 T caused by switching of the order parameter within the two dimensional space spanned by Qz and $Qx \sim x^2 - y^2$. A symmetry based analysis as well as mean field calculation of a phenomenological model show that the transition is due to competition between the magnetic Zeeman and the quadrupole interactions and the latter has highly non-linear field dependence. This peculiar and anisotropic variation of the quadrupole interaction with magnetic field is very surprising, which should be related to distinct features of the quadrupole Kondo coupling in this system.

O20-6

Incommensurate magnetism in heavy fermion systems

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Neutrons and muons were used to explore the magnetism of CeNiAsO and $CeAuSb_2$. In both cases the initial thermal instability of their heavy fermion state is to a long-wavelength amplitude-modulated incommensurate spin density wave (SDW).

Analyzing crystal field excitations, we show CeNiAsO is an easy plane system. There is a low-T transition to a commensurate non-collinear state that may result from bi-quadratic interactions. The commensurate phase is however, suppressed by P doping in CeNiAs1-xPxO prior to the transition to a Fermi liquid at xc=0.4.

Tetragonal $CeAuSb_2$ is Ising-like and the orthorhombic amplitude modulated incommensurate SDW is stable to the lowest T. A magnetic field applied along c yields an incommensurate 2-Q state.

Transport anomalies indicate significant modifications in electronic structure for both materials versus doping and field that we discuss considering this new information about spin correlations.

[1] Shan Wu and Guy Marcus are major contributors to this work that was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering under Grant No. DE-FG02-08ER46544 and DE-SC-0019331.

O20-7

Evaluation of chiral superconductivity in Sr_2RuO_4

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Through measurements under uniaxial pressure we have learned many new things about the superconductivity of Sr_2RuO_4. However its superconducting order parameter remains unresolved. The evidence that it is chiral remains compelling but not definitive. In this seminar, I will discuss results of heat capacity, muon spin rotation, and scanning SQUID microscopy measurements on Sr_2RuO_4 placed under uniaxial pressure, and their implication on the question of whether or not the order parameter is chiral.

O20-8

Spin current in quantum spin liquids and superconductions

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Various types of spin current has been found in condensed matter. Such currents give rise to various functions of matter, and they have led the recent progress of spintronics physics.

The firstly discovered spin current is so called conduction-electron spin current, detected in terms of the inverse spin Hall effect [1]. Secondly, we found spin-wave spin current in ferrimagnetic materials, in which spin waves carry angular momentum when their population is antisymmetric in the momentum space. Spin-wave spin current can also be created by heat current, which we named the spin Seebek effect. The concept of spin-wave spin current was expanded to other magnetically ordered phases such as antiferromagnets. Thirdly, we recently found that spin current can also be carried by spinons [2]; excitation from quantum spin liquid states.

In my talk, I will give an introduction to spin-wave spin current phenomena in antiferromagnets [3,4] with a well-defined Neel vector, spinon-spin injection into 1D quantum spin liquids, spin induced phenomena in antiferromagnets with DM interaction, and some related spin-current effects in antiferromagnets. This work was done with Dr. D. Hou, Dr. Z. Qiu, Dr. D. Hirobe, Dr. T. Kikkawa, Dr. K. Shiomi, Dr. K. Yamamoto, Prof. Y. Tserkovnyak, Prof. O. Gomonay, and Prof. G.E.W. Bauer.

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O20-9

Mapping the XY ferromagnet in d=2+1 onto electrodynamics

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Theory of the Kosterlitz-Thouless transition relies on a mapping of the XY ferromagnet in d=2 onto the classical theory of electrostatics, in which a vortex behaves like a particle with an electric charge equal to its winding number n. Thus vortices interact via a Coulomb potential with a logarithmic dependence on the distance. We extend the analogy to the dynamical phenomena in a d=2+1 spacetime. At low energies, the theory resembles the familiar electrodynamics with a background magnetic field. A careful examination of high-energy physics reveals that this particle also carries a magnetic flux proportional to the out-of-plane spin S_z of the vortex core (Figure 1). Braiding two identical vortices thus yields an extra phase of $2\pi nS_z$. Vortices with integer nS_z are bosons and those with half-integer nS_z are fermions.

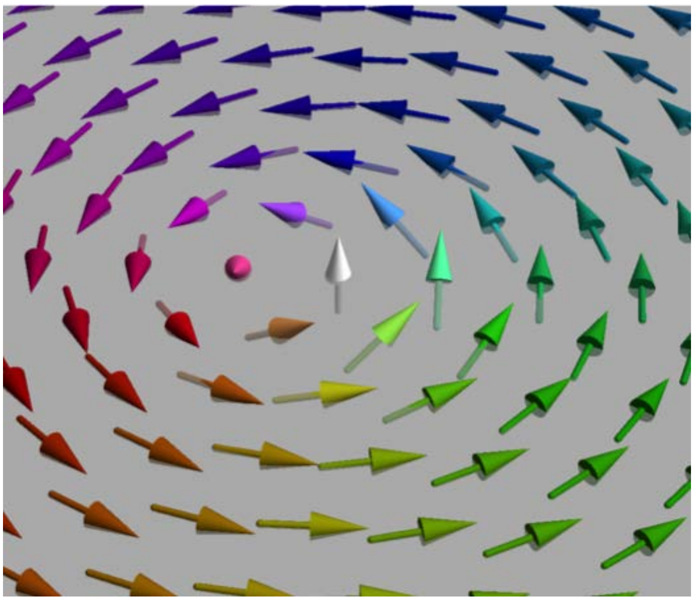

Figure 1: A vortex and its core.

O20-10

Shining (THz) light on quantum magnetic systems

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Interacting spin spin systems are considered paradigmatic examples of materials exhibiting quantum cooperative behavior. Of interest are various classical ground states where various forms of exchange and lattice symmetry conspire to give novel spin textures. Also of interest are various non-classical ground states in the form of spin-liquids that can be understood as systems with no order parameter, but macroscopic quantum mechanically entangled degrees of freedom. In this talk I will review recent work on this topic from my group using time-domain THz spectroscopy to probe the excitations of these systems. Such experiments allow us to do very detailed spectroscopy and reveal fine features of the magnetic spectra that might have been overlooked otherwise. I will cover material systems as diverse as $HoMnO_3$ (a classically ordered multiferroic that has an unconventional quartic Nd-Mn exchange as evidence by an unusual field dependence to the AF resonance), $FeSe_2S_4$ (a spin-orbital liquid with spin-orbital triplet excitations), $CoNb_2O_6$ (perhaps our best example of a 1D Ising chain) at the transverse field critical point, and $Yb_2Ti_2O_7$ (a quantum spin ice). In all cases THz spectroscopy reveals unique features that are hard to probe with other magnetic spectroscopies. I will also discuss our recent work using high field THz to not just measure, but to control spin systems.

P01

Thermal transport properties of S = 1/2 kagome frustrated Cd-kapallasite

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In recent years, the thermal Hall effect has gained a great interest as an important signature of the topology. This effect has been observed in paramagnetic phase of kagome antiferromagnets, volborthite[1] and Ca-kapellasite[2]. These thermal Hall conductivities (κ_{xy}) are shown to be well reproduced by Schwinger-boson mean field theory by tuning the Dzyaloshinskii-Moriya interaction (D) and the exchange interaction energy (J) as fitting parameters.

In my presentation, we report further evidence supporting the agreement between the experiment and theory from thermal Hall measurements in Cd-Kapellasite $CdCu_3(OH)_6(NO_3)_2 \cdot H_2O$[3] which has a smaller J/k_{B} (~ 45 K) than that of Ca-Kapellasite.

We find that κ_{xy} of Cd-Kapellasite shows a similar temperature dependence with that of Ca-Kapellasite, but the peak temperature is shifted to a lower temperature with a larger peak value. This difference is consistent with the smaller J/k_{B} of Cd-Kapellasite. The good scaling of these kagome materials strongly indicates that a kagome antiferromagnet has a common spin thermal Hall effect described by the Schwinger bosons[4].

In addition, we investigated the magnetic field dependence of the longitudinal thermal conductivity (κ_{xx}). Below 30 K, κ_{xx} normalized by the zero-field value ($\kappa_{nrm} = \kappa_{xx}(H)/\kappa_{xx}(0)$) is dramatically decreasing with increasing magnetic field. The decrease becomes larger as lowering temperature. As a remarkable feature, κ_{nrm} shows a hump around H = 7 T under 0.3 K whereas the field dependence of the heat capacity shows no anomaly at the field. This indicates a decrease of scattering of heat carriers at ~ 7 T.

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P02

Spin-density-wave transition and Seebeck coefficient in quasi-one-dimensional organic conductors

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In 2016, a huge magnitude of the Seebeck coefficient was found below the spin-density-wave (SDW) transition temperature ($T_{\rm SDW}$) in the quasi-one-dimensional organic conductor $(TMTSF)_2PF_6$ [1]. The property of the Seebeck coefficient can be divided into two regions with respect to temperature. In the high temperature region (1K<T<$T_{\rm SDW}$~12K), the magnitude of Seebeck coefficient first increases shows a peak around 1~2K, and then decreases by lowering temperature, i.e., it shows a dome structure as a function of temperature. In the low temperature region (T<1K), the Seebeck coefficient keeps increasing with lowering temperature. The purpose of our theoretical research is to clarify the behavior of Seebeck coefficient in the high temperature region.

The theoretical approaches based on the Boltzmann equation have succeeded in explaining various thermoelectric properties in metals [**]. However, the Boltzmann equation is applicable to good metals, so that it is inappropriate to use it below $T_{\rm SDW}$ since it is no more a good metal. On the other hand, there is no restriction for the approaches based on the Kubo formula. It is applicable both to metals and insulators.

In the present work, we calculate the thermoelectric coefficient by using the Kubo formula on the basis of the gravitational potential method first introduced by Luttinger [2] and improved by Jonson and Mahan [3]. We employ the effective tight-binding model of $(TMTSF)_2PF_6$ and take into account the opening of the SDW gap and the residual Fermi surface due to imperfect nesting condition [4][5]. In our calculation, the self-energy was taken to be constant and deviation of chemical potential due to impurities was considered. As a result, the dome structure observed in the high temperature region was explained quantitatively.

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P03

Theoretical study on magnetoresistance of SrTiO3

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It is well known that semimetals and multivalley systems show a magnetoresistance (MR) [1,2]. It is also well known that the system of single type of carrier with the closed fermi surface does not show the MR according to the conventional Boltzmann theory, even if the anisotropy of the fermi surface is taken into account [1]. Experimentally, however, all system of single type carrier with closed fermi surface show the MR. For example, $SrTiO_3$ (STO), which has a closed constant-energy surface at the Γ point, exhibits a clear MR experimentally [3]. The nature of this magnetoresistance has not been clarified yet.

Here, in order to solve this problem, we investigate the effect of the detailed structure of the Fermi surface, which is slightly deformed from a perfect sphere. We reformulate the conventional Boltzmann theory in order to take into account the arbitrary shape of the Fermi surface. The new formula so obtained is valid for a strong magnetic field region. First, we study the effect of the deviation from a sphere on the MR by using cubic harmonics to express the deviation. We found that a system with the single closed Fermi surfaces shows a clear MR due to the deviation from a sphere. Next, we employed the effective model of STO [4] and calculate its MR by the newly obtained formula. We obtained a clear MR for STO, which agrees with experimental results qualitatively.

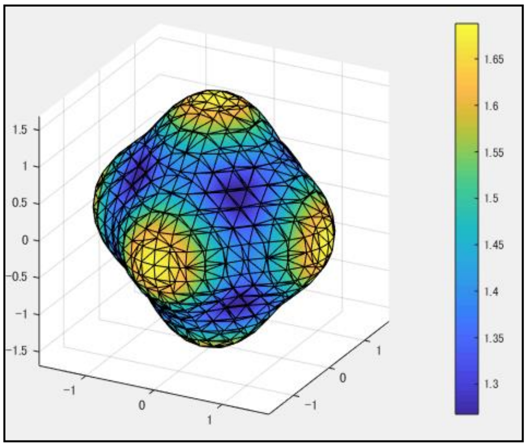

Figure 1: fermi surafece of STO
(n type,heavy electron)

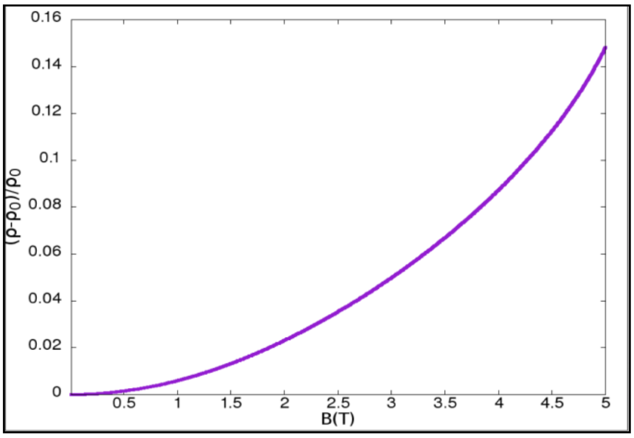

Figure 2: Magnetoresistance of STO
(Transverese)

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P04

Strongly anisotropic high temperature Fermi surface of the Kondo semimetal CeNiSn revealed by ARPES

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In heavy fermion system, the screening by the conduction electrons of magnetic moments yield by the f-electrons commonly gives rise to a metallic heavy Fermi liquid at low temperature. Namely, this is the Kondo effect in a periodic array of local moments. In terms of band structure, it can be described as the hybridization between a localized f-level and a conduction band, opening an indirect gap. Depending on the f-level filling, the chemical potential may lie within the gap: the expected low temperature metallic state gives way to an insulating phase. The family of Kondo insulators grew up in the last decades. However, with improvements made on samples quality, some members turn out to show semimetallic behavior at low temperature.

It is the case of CeNiSn which, with a coherence temperature as low as 8 K, was believed to be a narrow gap Kondo insulator, until its resistivity was found to form plateau at low temperature [1]. This semimetallic behavior has been ascribed to a node in the Kondo hybridization derived from a particular symmetry of the f-orbitals ground-state [2]. Here we carry out a 3D ARPES study in the high temperature regime to check whether or not the geometry of the CeNiSn conduction band is compatible with the nodal metal scenario.

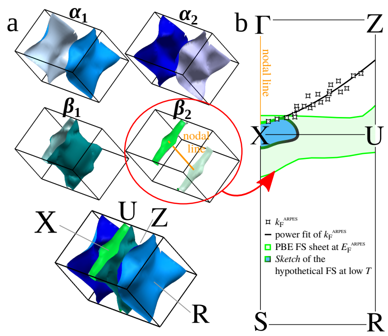

Figure 1: a. Fermi surface from Open core GGA+SOC calculations. b. 2D Fermi sheet at high temperature and expected low temperature modulation.

Highly anisotropic Fermi sheets are observed in the form of quasi-one and a quasi-two dimensional Fermi sheets, with a fairly good agreement with our Open core GGA+SOC calculations, Fig.1(a). We further claim the identification of the Fermi sheet involved in the semimetallic regime. We show how the expected nodal hybridization modulates this Fermi sheet to a small pocket compatible with the description from quantum oscillations, and with both the highly anisotropic magnetoresistance and the isotropic Nernst effect [3], as summarized by the Fig.1(b).

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P05

Laser-induced topological phase transitions in bilayer transition metal dichalcogenides

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Application of laser light can be a powerful tool for changing and controlling properties of materials. In recent years, topological phases in periodically driven systems by laser light have been actively investigated. For example, photoinduced quantum anomalous Hall states were theoretically proposed in laser-irradiated graphene [1,2] and the observation of this phenomenon was experimentally reported very recently [3]. It was also proposed that topological superconductivity can be induced with laser light in cuprate thin films [4].

Motivated by these situations, in this study, we theoretically investigate the laser-induced topological phase transitions in bilayer transition metal dichalcogenides (TMDs). Focusing on the transition metal ions, we can see that the TMD ' s 2H lattice structure is similar to graphene. The interlayer hopping of bilayer TMDs corresponds to the nearest hopping in graphene. Analyzing the tight-binding model for laser-irradiated bilayer TMDs with use of the Floquet theory, we show a topological phase transition in the band structure. We also examine the possibility of laser-induced topological superconductivity.

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P06

Local Magnetic Quadrupole Moments in Insulators

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Higher order multipole moments are important physical concepts as evident in multipole expansion of classical electrodynamics and multipole orderings in strongly-correlated electron systems [1,2]. In particular, magnetic quadrupole moments (MQMs) have recently been attracting much attention in relationship with the magnetoelectric effect [3-5].

Theoretically, quantum mechanical definition of MQMs is a difficult task. This is because the positon operator is ill-defined in the Bloch basis, which prevents us from an intuitive definition. Historically, such a problem also existed for orbital magnetic dipole moments, but has been resolved by considering a definition through thermodynamics [6]. Accordingly, recent theoretical work proposed thermodynamic definition of spin and orbital MQMs [7-10]. The obtained Bloch-basis formulas succeeded to clarify the connection between MQMs and the magnetoelectric effect: In insulators, chemical potential derivative of MQMs are equivalent to magnetoelectric coefficients. However, physical meaning of the Bloch-basis formulas is not obvious, since physical quantities should not depend on the chemical potential in insulators.

In this work, we clarify the relationship between the thermodynamic and classical definitions of MQMS, by considering systems with open boundary conditions rather than periodic boundary conditions. We illustrate the idea by showing charge movements in response to spatially modulated magnetic fields.

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P07

^{31}P-NMR study of pressure induced semiconductor – semimetal transition in Black Phosphorus

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The black phosphorus (BP), a layered material of elemental phosphorus, is a semiconductor with a narrow gap of 0.3 eV. The semiconducting gap of BP is reduced with pressure, and the semiconductor to semimetal transition occurs around 1.3 GPa [1]. This material has recently attracted much attention as a promising candidate for a pressure tunable Dirac system [2,3]. However the existence of a Dirac cone has not been experimentally corroborated yet, because there is little tools that allow one to investigate band structures under pressure.

In this study, we have carried out ^{31}P-NMR measurements on BP at ambient pressure and for the first time at high pressures. As nuclear spin-lattice relaxation rate $1/T_1$ is a physical quantity reflecting the density of states (DOS), we expect to extract information on the gap structure in the DOS and also the pressure dependence of the gap by measuring the temperature dependence of $1/T_1$ at different pressures. However, T_1 of BP reaches 1.4×10^4 sec at 77K and ambient pressure. For such a ling T_1, we needed careful measurement to obtain reliable data especially at low temperature. We have also performed band structure calculation using the local density approximation (LDA). The comparison with simulations based on DOS models consisting of the band structure obtained from the LDA calculation and an additional impurity band shows that the temperature dependence of $1/T_1$ is explained as the sum of components caused by carriers thermally excited over gaps between the valence and conduction bands and between the valence and impurity bands. By applying the DOS model to the analysis of the data up to 0.83GPa, we estimated the pressure-induced variation of the gap structure. Moreover we will show experimental results in the semimetal phase above 1.6 GPa to discuss the possible realization of Dirac cone like structure.

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P08

Transitions of topological spin textures between skyrmion- and hedgehog-lattice states in cubic chiral magnets $MnSi_{1-x}Ge_x$

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Topological spin textures such as magnetic skyrmions[1] and spin hedgehogs[2] show novel emergent phenomena which can be exploited for spintronic functionalities. Whereas creation or deletion of them have been intensively studied, switching of spin textures among different topologically-nontrivial classes remain largely unexplored.

We report on the transitions among skyrmion- and hedgehog-lattice states in cubic chiral magnets $MnSi_{1-x}Ge_x$ with variation of lattice constant controlled by Si/Ge substitution. By combining neutron scattering, Lorentz transmission electron microscopy and high-field transport measurement, we observe three different topological spin textures: skyrmion lattice in x = 0-0.25 as well as two distinct hedgehog lattices in x = 0.3-0.7 and x = 0.8-1, as respectively characterized by large topological Hall effect.

The emergence of various topological spin states in the chemical-pressure-controlled materials suggests a new route for direct manipulation of the spin-texture topology by facile mechanical method such as pressure.

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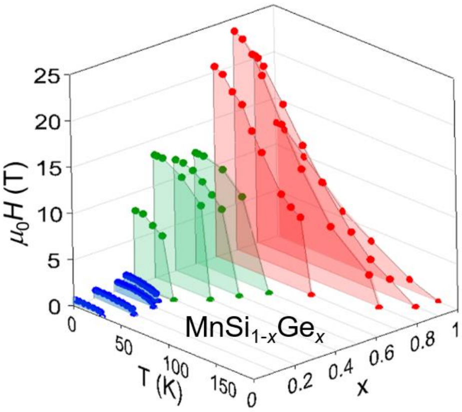

Figure 1: Variation of magnetic phase diagram in $MnSi_{1-x}Ge_x$.

P09

Topological lightwaves for optical physics

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Topology is of paramount importance for modern physics. From electronic band structures to the rigidity of origami, the concept of topology ubiquitously roles, continuously improving our understanding of the physics of electrons, spins, phonons, and photons.

Topology of photons usually refers to that of photonic band structures in photonic crystals. How about that of propagating photons, i.e. lasers? In optics, a study of lightwaves with topological nature has developed in the past decades. Those "structured" lasers have been utilized for microscopes, optical tweezers, laser ablation, laser acceleration, and so on. Unfortunately, optical physics, a study of light-matter interaction, has been noninteracting with those developments.

We have been working at the intersection of the optical physics and the structured light optics [1, 2, 3, 4], proposing potential applications of the topological lightwaves such as optical vortex, a lightwave carrying orbital angular momentum, and cylindrical vector beam, a laser with vortical polarization for optical physics. We found that optical vortices would be useful in systematically generating various topological magnetic defects in chiral magnets and in controlling the nonequilibrium spin texture in an unconventional way.

In this presentation, we particularly focus on our recent works on cylindrical vector beams (CVBs) [3, 4]. Due to their characteristic spatial profile and the focusing property, CVBs allow us to control the electric and magnetic field components of them in a way impossible for conventional lasers. We show that this unique feature of CVBs potentially has substantial impact on condensed-matter physics. We show that with CVBs, we would be able to measure the Fermi surface of magnetic metals, perform high-frequency magnetic resonance study of semiconductors, control "electromagnonic" excitations of multiferroics, and so on. We also demonstrate that CVBs offer a ideal building block for designing nonequilibrium states of matters through Floquet engineering.

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P10

Dzyaloshinskii-Moriya interactions in volborthite: magnetic orders and thermal Hall effect

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Volborthite $Cu_3V_2O_7(OH)_2\,2H_2O$ offers an interesting example of a highly frustrated quantum magnet in which ferromagnetic and antiferromagnetic interactions compete on anisotropic kagome lattices. A recent density functional theory calculation has provided a magnetic model based on coupled trimers (Fig. 1(a)) [1], which can explain a broad 1/3-magnetization plateau and possible bimagnon condensation observed experimentally. Here we study the effects of Dzyaloshinskii-Moriya (DM) interactions in this compound. By means of a strong-coupling expansion, we derive an effective model in which pseudospin-1/2 moments emerging on trimers form a network of an anisotropic triangular lattice (Fig. 1(b)). We show that magnon excitations from the 1/3-plateau (fully polarized pseudospins) feel a Berry curvature due to the DM interactions, giving rise to a thermal Hall effect. Comparison with experiment poses constraints on the coupling constants in the effective model. We also analyze magnetic orders at low temperatures in light of an effective field theory for a quasi-one-dimensional regime.

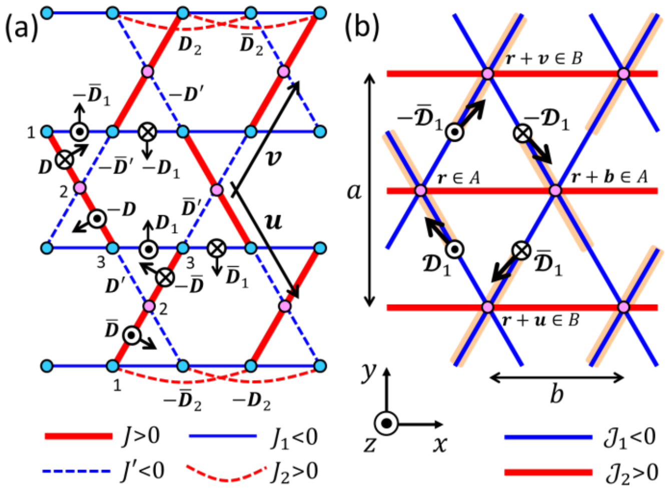

Figure 1: Schematic diagrams of (a) the microscopic spin-1/2 model and (b) the effective pseudospin-1/2 model for a single layer of volborthite. In defining DM vectors, every bond is oriented from left to right, and an arrow (a dot or a cross) indicates the in-plane (out-of-plane) component. A bar on a DM vector indicates π rotation around the x axis.

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P11

Flat-Band Compound as a Possible Candidate of Topological Material

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Flat-band system has been paid much attention because it will emerge many anomalous properties, such as exact ferromagnetism, superconductivity, quantum Hall effect, and so on[1]. Among them, quantum Hall effect appears as a direct consequence that the band has non-trivial topological nature. Even fractional quantum Hall effect is predicted for the flat-band system. However, although many theoretical researches have been conducted on the flat-band model, almost no compounds have been found to realize this flat-band system even approximately.

By performing *ab-initio* band calculation, we have recently found that pyrochlore oxides $A_2B_2O_7$ (A=Sn,Pb; B=Nb,Ta) have a quasi-flat band at the top of the valence band[2,3]. This band comes from the A-s and O'-p orbitals, and the band structure can be approximated by Mielke model, which is one of the models having flat-band. Moreover we found that when holes are doped, these compounds will have ferromagnetic ground state despite having no magnetic element. We also found that some of the bands of $Sn_2Nb_2O_7$ and $Sn_2Ta_2O_7$ are "reversed", due to the different strength of the spin-orbit interaction.

In this conference, we will present our study for exploring the flat-band compounds which are potential candidates of topological and/or magnetic material.

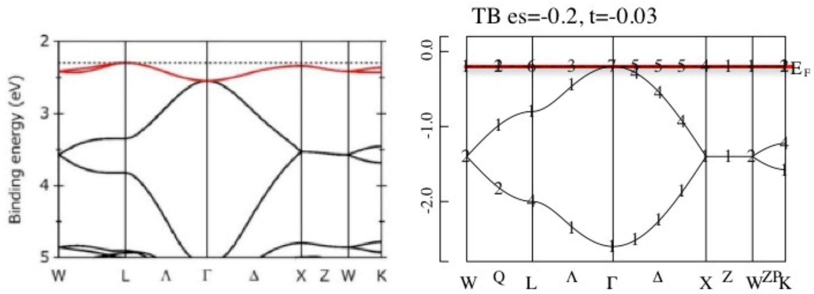

Figure 1: (left panel) The top of the valence band of $Sn_2Nb_2O_7$. (right panel) Corresponding band structure of the Mielke model. The bold red lines depict the (quasi-) flat band.

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P12

Spin-orbit coupled insulator Ba_2MgReO_6

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Materials with a strong spin-orbit coupling and large electron correlation have received great interests in recent years because of their exotic properties including Weyl semimetals, axion insulators, topological Mott insulators, and multipolar orders [1]. Among these spin–orbit-coupled metals and insulators, a material realization of multipolar orders is theoretically proposed in double perovskite compounds with the d^1 electronic configuration [2]. Ba_2NaOsO_6, a representative material in this family, shows an unusual magnetically ordered phase at low temperatures, which is consistent with the theoretical prediction [3,4]. However, a quadrupole ordered phase expected to exist above the magnetic order has not been experimentally confirmed yet.

Here, we report on the cubic double perovskite Ba_2MgReO_6 containing Re^{6+} ions in the $5d^1$ electron configuration as a promising candidate of the spin-orbit coupled insulator hosting the quadrupolar order. Resistivity, magnetization, and heat capacity measurements using single crystals show that the compound is a Mott insulator with a magnetic transition at T_m = 18 K and another transition at T_q = 33 K (Fig. 1b). The significance of spin-orbit coupling is revealed by the reduced effective magnetic moment of ~0.68 μ_B at high temperatures above T_q and the total electronic entropy close to Rln4. These features indicate that Ba_2MgReO_6 is a spin-orbit coupled Mott insulator possessing a J_{eff} = 3/2 quartet state, which exhibits quadrupole and dipole orders at T_q and T_m, respectively.

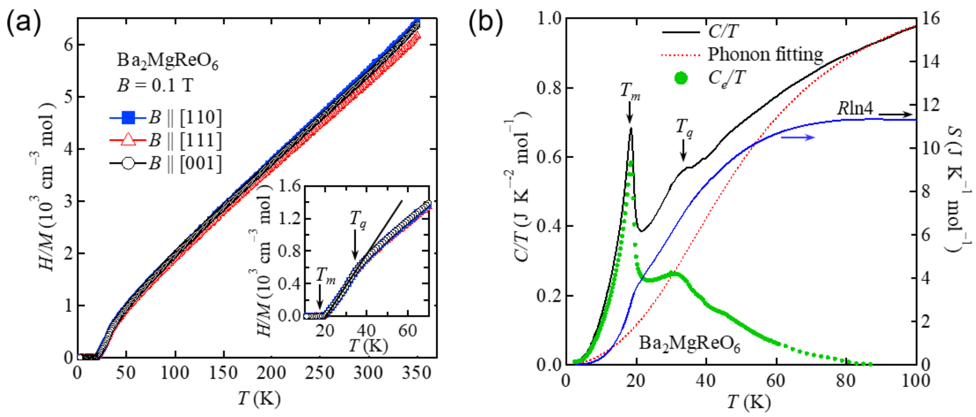

Figure 1: Temperature depdndence of (a) invserse of magnetic susceptibility and (b) heat capacity of Ba_2MgReO_6.

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P13

Skyrmion formation and enhanced emergent electrodynamics in centrosymmetric magnets

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*: equal contribution

Research on magnetic skyrmions, which are nanometric whirls in non-collinear magnets, has long been focused on non-centrosymmetric compounds (such as the B20 family) or interfaces, where Dzyaloshinskii-Moriya interactions favor twisted spins structures with fixed helicity.

We report on our recent experimental efforts to study skyrmion formation and associated transport responses in centrosymmetric magnets, where DM interactions are absent or cancel out globally, and where left- and right-handed spirals are nearly degenerate. Here, spiral spin structures are stabilized by RKKY interactions and the size of a single skyrmion is typically smaller than 3 nm, resulting in a giant emergent magnetic field detectable by means of the topological Hall effect.

P14

Multipolar DM interaction in 5d electron systems

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The collaboration between strong spin-orbit coupling and strong electron correlation attracts much attention due to many physically interesting phenomena. $5d$ electron systems offer an ideal arena to investigate this collaboration on account of their strong spin-orbit coupling. Recently, $5d^5$ electron systems such as iridium based compounds have been enthusiastically studied. Examples include Sr_2IrO_4, which shows an unconventional metal-insulator transition [1], and Na_2IrO_3, which is proximity to the Kitaev spin liquid [2]. These materials have the half-filled band of $j_{\mathrm{eff}} = 1/2$ doublet, which is constructed from t_{2g} orbitals with pseudo angular momentum $l_{\mathrm{eff}} = 1$.

In contrast to $5d^5$ systems, $j_{\mathrm{eff}} = 3/2$ quartet becomes active in $5d^1$ systems. Remarkably, not only dipolar moment, which corresponds to usual spin degree of freedoms, but also higher-rank multipoles such as quadrupole and octupole become active for $5d^1$ systems due to its fourfold orbital degree of freedom. Indeed, these multipoles induce many exotic phases such as the quadrupolar ordered phase in a double-perovskite material Ba_2NaOsO_6 [3].

It is even more interesting if we consider the effects of spacial inversion symmetry breaking (ISB). If the system has magnetic dipole moments, the lack of spacial inversion symmetry induces anti-symmetric exchange interaction, i.e. the Dzyaloshinskii-Moriya (DM) interaction. For 3d systems, the DM inrteraction has been evaluated precisely by first principles calculations. On the other hand, for $5d^1$ systems, which have the higher-rank multipolar degrees of freedom, we expect that there exist the analogues of DM interactions for the higher-rank multipoles, which can lead to novel phases with chiral multipole orders.

In this poster presentation, we study anti-symmetric exchange interactions between multipolar moments using exact diagonalization method on two-site multiband Hubbard model. We discuss two types of configuration of octahedron AO_6 (A : $5d$ ion), corner-sharing and edge-sharing configuration. The corner-sharing figuration appears in perovskite type crystal structure and edge-sharing one in hyperkagome or post-perovskite crystal structure. We will show the existence of DM interaction between the dipoles of $j_{\mathrm{eff}} = 3/2$, as well as between higher-rank multipoles that consist of products of j_{eff}-operators for both confugurations.

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P15

Mechanism of superconductivity in Kondo lattice with semi-metallic conduction bands

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Non-local and anisotropic Cooper pairings are usually favored in heavy-electron materials with nearly localized f-electron. On the other hand, the full-gap nature of the superconducting states in $CeCu_2Si_2$[1] and UBe_{13}[2] have been revealed by the specific heat measurements in a rotating magnetic-field. Therefore it is desirable to propose a new mechanism of superconductivity that is specific to heavy-electron materials.

Here we theoretically study the Kondo lattice with semi-metallic conduction bands, where conduction electrons and conduction holes compete in screening the localized spin moment. Based on the mean-field approach, we reveal that the quantum mechanical superposition between electron conduction band and hole conduction band is realized through the formation of the Kondo-singlet states (Fig.1). The resultant ground state spontaneously breaks the gauge symmetry to make the system superconducting. This superconducting state is characterized by the composite pairing amplitude, which has been proposed in the context of two-channel Kondo lattice[3]. We have demonstrated here that the semi-metallic conduction bands with electron and hole Fermi surfaces are closely related to the composite pairing. In addition, we discuss the possible application to real heavy-electron materials.

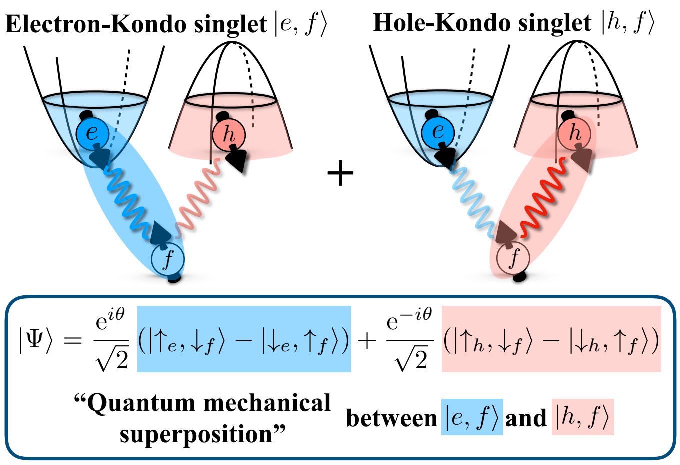

Figure 1: Conceptual picture of the mechanism of superconductivity in Kondo lattice with semi-metallic conduction bands.

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P16

Supercurrent-induced Edelstein effect

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Controlling of magnetic moments using local electric current is an important topic in the modern field of spintronics. One of the representative methods is the Edelstein effect [1], in which an electrical current generates nonequilibrium spin density through a splitting of the Fermi surface in noncentrosymmetric metals with strong spin-orbit coupling, e.g. interface Rashba systems [2, 3]. However, for practical applications, e.g. domain rotation and reversible magnetization switching [4], large amount of current density (7×10^5[Acm^{-2}]) is needed. Therefore, Joule heating created by dissipative current is a main obstacle for efficient control of magnetization.

In this study, we suppose that the surface state of d-wave superconductors is a good candidate for efficient magnetization control. D-wave superconductors show topologically nontrivial properties [5], and is accompanied by unique surface band structure, e.g. Majorana flat band in its edge mode [6]. Using theoretical framework for the dissipationless supercurrent [7, 8], we examine the supercurrent induced Edelstein effect by tight-binding model calculations.

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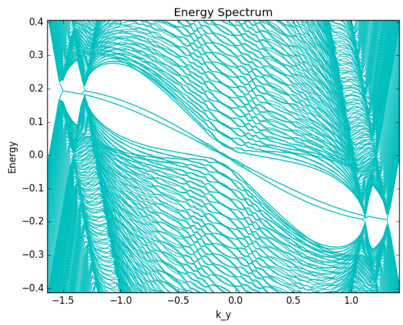

Figure 1: Surface states of current flowing d-wave superconductor

P17

Excitonic condensation in correlated cobaltite $LaCoO_3$ at ultrahigh magnetic field

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In a cobaltite, LaCoO3, the spin-state degree of freedom of Co+3 (d6) varies from high (HS), intermediate and low spin states (LS) with S=0, 1, 2, respectively, due to the balance of Hund's coupling and crystal field splitting. A first order magnetic transition induced by magnetic field at 60 T is reported [1] from a non-magnetic ground state to a magnetized state, whose origin is still unclear. Besides, by constructing B-T phase diagram, we recently clarified that the magnetic phase is divided into two phases separated by the temperature of ~30 K [2].

Theories argue that the field induced magnetic phase may be originated in the excitonic condensation. Those exotic phase appears in cobaltites as a result of the spontaneous hybridization of LS and HS states [3-5]. In excitonic condensation, the multipole order of spin and orbitals are realized as a result of the interference between different spin states, which sometimes involves nematicity of spin and orbitals. The field induced phase does not contain the nematicity of spin and orbitals in the ideal limit where spin-orbit interaction is absent which is not true for the actual cobaltite.

In the present study, we have investigated the high magnetic field phase diagram of LaCoO3 with magnetostriction measurements. We have developed a high speed magnetostriction measurement system for detecting the spin-state evolution of LaCoO3 [6]. So far, we have confirmed that the B-T phase diagram of LaCoO3 constructed by the magnetization measurement is complemented by the magnetostriction measurement.

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P18

Magnetic Phases of Non-collinear Antiferromagnet Mn_3Sn

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The metallic antiferromagnet Mn_3Sn with triangular spin structure exhibits large anomalous Hall effect[1], anomalous Nernst effect[2], and spontaneous magneto-optical Kerr effect[3], comparable to ferromagnets. Conventionally, such behaviors are unexpected in antiferromagnets with vanishing magnetization. However, it is known that spontaneous off-diagonal electronic responses can appear in antiferromagnets whenever the symmetry of the antiferromagnetic structure is equivalent to collinear ferromagnets[4]. The unique electronic properties of the triangular spin structure, combined with the low magnetization and terahertz spin dynamics, make Mn_3Sn a promising material for spintronic devices. In its bulk form, Mn_3Sn single crystals are reported to be stable within a range of Mn compositions, $Mn_{3+x}Sn_{1-x}$. Depending on the initial composition and growth condition, three distinct kinds of magnetic phases can be stabilized as a function of temperature, namely the high-temperature triangular spin structure phase[5], the intermediate helical phase[6], and the low-temperature cluster spin-glass phase[7]. Here we report the magnetic phase diagram of Mn_3Sn as a function of Mn composition using magnetization and transport measurements. We found that the helical phase is the intrinsic ground state of Mn_3Sn, and the excess Mn extends the parameter region of the triangular spin structure on the phase diagram.

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P19

Rectification of Spin Current in Magnetic Insulators with Linearly-Polarized Electromagnetic Waves

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Manipulation of magnetic states and spin current is a key subject in spintronics [1]. In conductive materials, the charge current is often used for such purposes; magnetic domain walls are moved by spin-transfer effect and spin Hall effects are used to generate spin current. The concept of spintronics is also applied to magnetic insulators, which have several advantages over the conductive materials: Magnetic excitations typically have a longer lifetime and no ohmic loss in the insulators. A technical challenge, however, exists in controlling the magnetic excitations which carry the angular momentum in the magnetic insulators; manipulating the magnetic excitations are not as easy as electrons because they are chargeless. Recent studies on opto-spintronics found that electromagnetic waves are a useful tool for controlling the magnetic states. On the other hand, the method for manipulating spin current in magnetic insulators is limited to ferromagnets, i.e., by spin pumping.

In this work, we explore a method for generating dc spin current in antiferromagnetic insulators (Fig. 1). By considering a noncentrosymmetric spin chain, we theoretically show that a dc spin current is induced by a linearly-polarized electromagnetic wave [2]. In particular, we find that three coupling terms between the spins and electromagnetic waves give rise to the spin current: Inverse Dzyaloshinskii-Moriya, Zeeman, and magnetostriction couplings. The rich microscopic mechanisms are reflected in the anisotropy and frequency dependence of the induced spin current. We discuss that the spin current is a consequence of the non-trivial shift of magnetic excitations during the quantum transition by the electromagnetic wave. This spin current potentially provides a method for fast control of spin current in antiferromagnets.

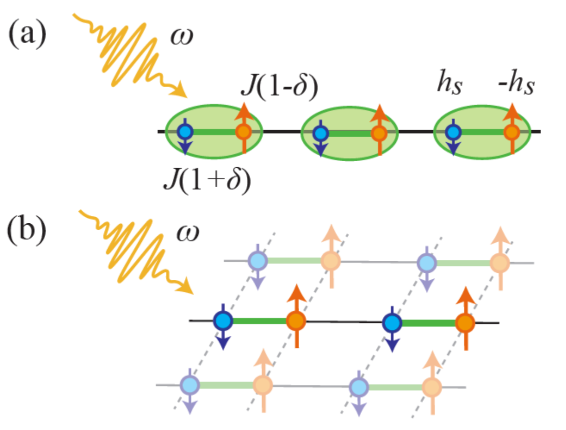

Figure 1: The setup we consider in our theory. The model we consider applies to (a) 1d spin chain as well as (b) to a weakly coupled spin chain.

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P20

NQR Study of Multipole orders in PrT_2Al$_{20}$ (T=Ti, V)

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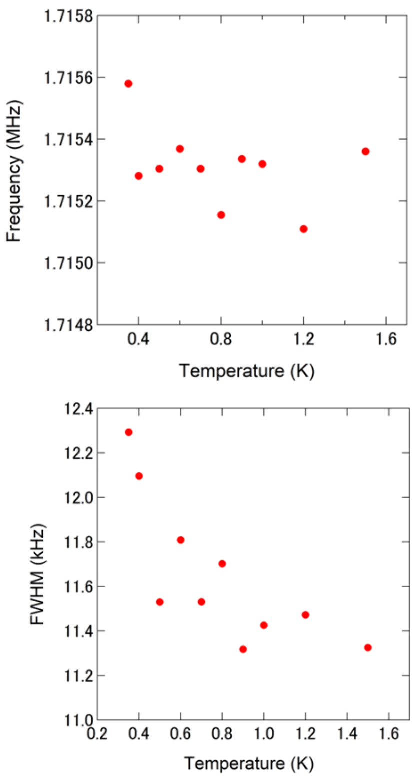
Materials containing non-kramers Pr^{3+} ions provide a rich research field on multipole physics in f-electron systems, of which PrT_2Al$_{20}$ (T=Ti,V), are promising candidate. They have non-magnetic Γ_3 doublet ground state in the cubic crystaline electric field with zero magnetic dipole but finite electric quadrupole and magnetic octupole moments. A $3z^2$-r^2 type ferro-quarupole order occurs in $PrTi_2Al_{20}$ at 2 K with concomitant switching of quadrupole order parameter in magnetic fields as discovered by the recent NMR experiment [1]. On the other hand, PrV_2Al_{20} with stronger c-f hybridization exhibits more complex phenomena, such as non-Fermi liquid behavior suggestive of quadrupole Kondo effects, double phase transitions in temperature, and magnetic-field-induced phase transitions.

Here we present results of ^{27}Al-NQR measurements on single crystals of PrT_2Al$_{20}$ (T=Ti, V) to detect symmetry breaking and fluctuations associated with multipole order. Breaking of crystalline symmetry due to ferro-quadrupole order in $PrTi_2Al_{20}$ has been detected as NMR line splitting caused by anisotropic hyperfine field in magnetic fields [2]. We are now trying to detect symmetry lowering of the electric field gradient by zero-field NQR. In PrV_2Al_{20} possible octupole order, as has been theoretically considered [3], may generate spontaneous hyperfine magnetic field even at zero field. The right figure shows the temperature dependence of NQR frequency and the line width at the Al(3) sites in PrV_2Al_{20}. Although there is no change in the NQR frequency, the line width increases gradually below 1K.



Temperature dependence of NQR frequency and the line width

[1] T. Taniguchi *et al.*, in preparation.
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[3] F. Freyer *et. al.*, Phys. Rev. B **97** (2018) 115111.

P21

Anomalous Zeeman effect in strongly spin-orbit coupled systems

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Topological materials exhibit specific properties which cannot be classified by the conventional band theory. Recently, a lot of experiments and theories on the topological materials, such as topological insulators and Weyl semimetals, were reported. Many topological materials possess the Dirac electrons (or Weyl electrons), which have linear dispersions. One of the typical way to judge the existence of Dirac electrons to observe the linear dispersion by the ARPES measurements or by the first principles calculation. However, the linear dispersions do not grantee the existence of Dirac electros. In order to evaluate how the electrons in crystals are close to the "true" Dirac electrons --- "Diracness"---, it would be most useful to measure or calculate a ratio of the Zeeman splitting to the cyclotron energy ($M=E_z/E_c$)[1]. Experimentally, the ratio M can be determined by the measurement of quantum oscillations. Theoretically, M ca be determined by calculating the energy levels under a magnetic field. In principle, the energy levels under a magnetic field can be precisely calculated based on the *k.p* theory as was shown by Luttinger and Kohn [2]. In practice, however, it is too complex to calculate the energy levels of a specific solid because of the noncommutativity of the kinematical momentum operator π ($=p-eA$), which does not allow us to use the simple diagonalization technique. Even today, the energy levels under the magnetic field for multiband system can be obtained perturbatively using the Löwdin partitioning [3]. In this study, we introduce a new numerical technique to calculate the energy levels under the magnetic field exactly by considering the noncommutativity of π. By using this technique, we show that the ratio M, which has been believed to be independent from the magnetic field, exhibit a remarkable field dependence as shown in Figure 1.

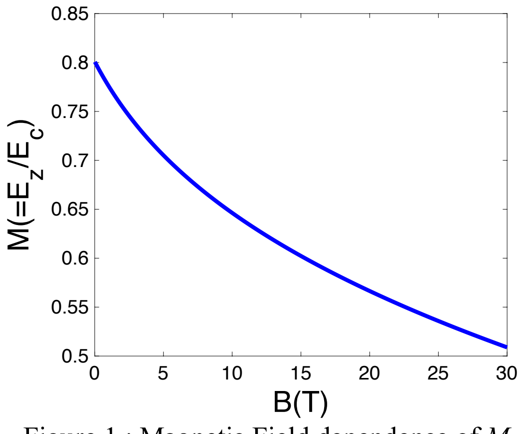

Figure 1 : Magnetic Field dependence of M

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P22

Coupled Spin-Charge Fluctuation in the Semimetal Phase of All-In/All-Out Antiferromagnet $Cd_2Os_2O_7$

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It is inferred from muon spin rotation experiment that the all-in/all-out osmium spin structure realized in the antiferromagnetic phase of a pyrochlore compound $Cd_2Os_2O_7$ (with the Néel temperature $T_N \simeq 227$ K) serves as a stage of novel electromagnetic fluctuation over the temperature range between $T^* \simeq 150$ K and T_N, where T^* marks the Lifshitz transition between semiconductor ($T < T^*$) and semimetal ($T > T^*$) phases[1]. Strong muon depolarization observed upon substitution of Os ($5d^3$) with small amount of Re ($5d^2$) [$Cd_2(Os_{1-x}Re_x)_2O_7$ with $x = 0.01$–0.03] indicates that the magnetic fluctuation is coupled with the mobile holes in the semiconductor phase, which is drastically enhanced by intrinsic carriers in the semimetal phase. Remarkably, the relevant spin-charge dynamics is hidden to other magnetic probes such as magnetic susceptibility[2], NMR[3], and resonant x-ray diffraction[4], demonstrating its unique time scale of 10^{-7} to 10^{-10} s^{-1} with a soliton-like character of propagation associated with the Ising-like local anisotropy.

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Spin-orbit-coupled ferroelectric superconductivity and multiorbital effects in doped $SrTiO_3$

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$SrTiO_3$ (STO) is a rare example of a system in which superconductivity and dielectricity is closely related. The quantum paraelectric STO exists in the vicinity of a ferroelectric (FE) quantum critical point[1]. Therefore, STO becomes a FE by chemical substitution or application of stress. On the other hand, slightly doped STO exhibits metallic behavior with superconducting instability at low temperatures[2]. The pairing mechanism of superconducting STO is a long-standing problem of the condensed matter physics, since it occurs in an exceptionally low carrier density region where the Migdal-Eliashberg approximation is not appropriate. Although the FE quantum criticality and superconductivity in STO have been considered to be unrelated for a long time, their close correlations are pointed out these days[3]. For example, a coexistent phase of FE-like order and superconductivity, namely FE superconducting phase, have been discovered in Ca-substituted and carrier doped STO[4].

Motivated by recent studies about the correlation between FE quantum criticality and superconductivity in STO, we investigated the stability of the FE superconducting phase by using a multiorbital model for bulk STO[5]. Since FE phase transition breaks the inversion symmetry and induces antisymmetric spin-orbit coupling (ASOC), we assumed a proportional relationship between the FE order parameter and the strength of ASOC[6]. It is shown that the FE superconducting phase is stabilized even though the normal state is paraelectric. We will show that the stabilization of the FE superconducting phase is caused by the Lifshitz transition induced by the ferroelectricity. In addition, it is demonstrated that the upper critical field of the FE superconducting phase is drastically enhanced thanks to the ASOC and multiorbital effect.

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P24

Enhanced Thermopower in Hole-doped Pyrochlore Iridates with Quadratic Band Touching

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2 *RIKEN Center for Emergent Matter Science (CEMS), Japan*

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5 *PRESTO, Japan Science and Technology Agency, Japan*

Quadratic band touching (QBT) is a band structure in which the parabolic valence and conduction band touch at a point, protected by spatial and time inversion symmetry. The possibility that QBT becomes the source of exotic electronic phases such as Weyl semimetal has been discussed. The existence of QBT has been confirmed in $Pr_2Ir_2O_7$ (PIO)[1], which is a member of pyrochlore-type iridate $R_2Ir_2O_7$ (RIO, R=Rare earth). Since QBT in PIO is stabilized by the crystal symmetry, we can consider the possibility of the universal existence of QBT in the paramagnetic metallic phase of RIO. Therefore, we made hole-doped samples of insulator $Eu_2Ir_2O_7$ to compare its electronic properties with PIO.

Using the transport measurement and ab-initio calculation, we have explored the thermopower and electronic structure of correlated metal with QBT in hole-doped pyrochlore iridates. We found that the hole-doped QBT yields a thermopower peak, which can be enhanced exceeding 40 V/K below 50 K by tuning the band-filling and lattice distortion. The thermopower peak is observed even in the doping induced metallic phase created from Mott insulator, indicating that the QBT is robust against the strong electron correlation as well as the lattice distortion while keeping the cubic symmetry.

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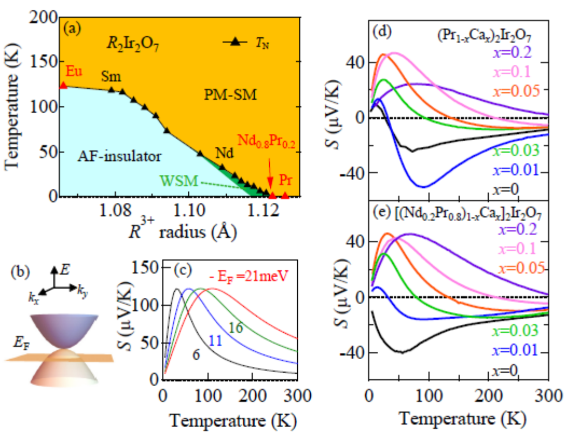

Fig. Phase diagram and representative transport property of $(R_{1-x}Ca_x)_2Ir_2O_7$

P25

Assessing the numerical accuracy of tensor-network representation of the Kitaev spin liquid

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The Kitaev honeycomb model is one of the rare two-dimensional integrable systems in which the ground state is a spin liquid [1]. Iridium and ruthenium compounds are promising candidates for realizing the Kitaev model [2, 3]. However, the effective models of real compounds may deviate from the original Kitaev model and include additional spin exchange interactions that could stabilize magnetic order at low temperatures [4–6]. General-purpose numerical methods are needed for investigating the phase diagram of the generalized Kitaev-like model where the Heisenberg and off-diagonal exchange interactions are present.

To this end, we focus on the tensor-network method in two-dimensional systems and investigate its applicability to the simplest isotropic ferromagnetic Kitaev model. In particular, we use the tensor product state (TPS) or the projected entangled-pair state (PEPS), which is described in the spin degrees of freedom, as a variational wave function and obtain the ground state in the thermodynamic limit by imaginary time evolution (ITE). In the previous study, a higher-cost ITE (full update) was thought to be indispensable [7]; however, this requires at least $O(D^{10})$ computational cost with D being a bond dimension for optimization. By contrast, we have found that a lower-cost ITE (simple update), which only requires $O(D^5)$ cost, is sufficient to represent the gapless spin liquid when the initial TPS is carefully chosen according to the required physical symmetries as well as the zero-flux configuration of the $\mathbb{Z}_2$ gauge field. We discuss how to construct such an optimal TPS for $D = 2$ and how the energy is improved as D is increased. We also report the stability of spin liquid obtained by numerical optimization against perturbations such as the Heisenberg exchange interaction and the magnetic field.

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P26

Rashba-Dresselhaus effect in magnetic insulators

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In electronic systems, the spin-orbit coupling induces a spin and a momentum dependent band splitting called Rashba-Dresselhaus effect. So far, this kind of phenomena were rarely observed in magnetic insulators, although their low energy excitations are governed by magnons carrying a spin momentum. Few cases show magnon band splitting[1] and spin textures in momentum space is theoretically proposed but only in a rather unrealistic situation[2]. This is because the $SU(2)$ spin degrees of freedom in electrons that can couple to orbital motions is not present in usual magnets. Here, we show that the inversion-symmetry broken two-sublattice antiferromagnets can overcome this issue in a natural manner by making use of the two-sublattice degrees of freedom as pseudo-spins[3]. We construct the $SU(2)$ degrees of freedom within the product space of the particle-hole and two-sublattice degrees of freedom, and find that the Dzyaloshinskii-Moriya interaction (DMI) couples the pseudo-spin and space motions of magnons and generates a magnon band splitting and spin textures in momentum space(Fig.1), which are regarded as the Rashba-Dresselhaus effect of magnons. We also classify a role of the DMI, and present a systematic way to design spin textures in momentum space.

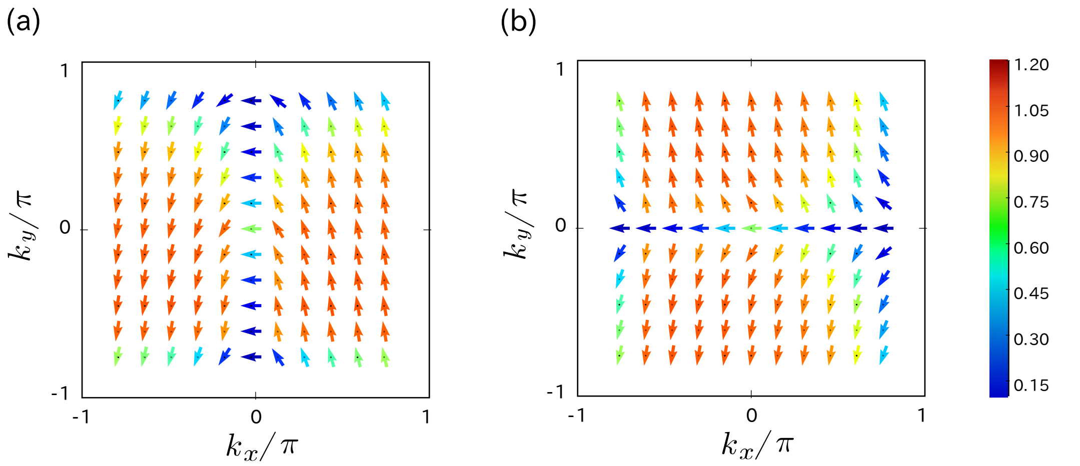

Figure 1: (a) Rashba-type and (b) Dresselhaus-type spin texture of a lower magnon band over the first Brillouin zone.

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P27

Field-orientation effect on the hidden-order transition in URu_2Si_2

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The mechanism of a hidden-order transition in URu_2Si_2 [1] is a long-standing mystery in condensed-matter physics. At the transition temperature T_O (~17.5 K), the specific heat shows a sharp jump [2] and the Ising-like moment along the easy *c* axis shows a kink [3], demonstrating that it is a second-order transition. However, no clear symmetry breaking has been found at T_O in spite of a great amount of experimental and theoretical studies. The nature of the hidden-order phase is also important to uncover the pairing mechanism of unconventional superconductivity occurring below 1.4 K, whose gap symmetry is likely to be a chiral *d*-wave type [4]. Recently, a possibility of tetragonal symmetry breaking in the hidden-order phase has been proposed on the basis of the results of magnetic torque, cyclotron resonance, and X-ray diffraction measurements [5, 6], and is still under intense debate.

In order to obtain further evidence for the tetragonal symmetry breaking in the hidden-order phase, specific-heat measurements would be powerful because it shows a very sharp transition at T_O. To examine the in-plane rotational symmetry, however, precise control of the magnetic-field orientation might be essential because URu_2Si_2 has an Ising-like anisotropy. In this study, we have developed a home-built calorimeter [7] whose addendum is fixed strictly in order to prevent the sample from tilting by strong magnetic torque, and first investigated the field-angle dependence of T_O under a magnetic field rotated within the *ac* plane. Then, we found a cosine-like function in its field-angle dependence. In future work, we will examine the breaking of tetragonal symmetry of the hidden-order transition via specific-heat measurements under a rotating magnetic field which is precisely applied along the *ab* plane by means of this cosine-like out-of-plane anisotropy.

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P28

Synthesis and magnetic transport properties of antiferromagnet Mn*X* (*X* = Sn, Ge) thin films

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Antiferromagneic materials have recently attracted much attention as the next generation spintronic device in surge of demand for higher integration density and faster data processing devices. The advantages of antiferromagnets are such as negligible stray field and high-frequency magnetization dynamics [1]. However, it is difficult to electrically detect or externally manipulate the Neel state because of the absence of magnetization in these materials.

On the other hand, recently, surprisingly large spontaneous transverse responses have been found in noncollinear kagome-lattice antiferromagnets $D0_{19}$ Mn_3X (X = Sn, Ge). They exhibit large anomalous Hall [2-5], anomalous Nernst [6], and magnetic optical Kerr effects [7] at room temperature. Not only for bulk crystal systems, but Mn_3Sn thin film has also been confirmed to show the similar large responses [8], which shall make a significant progress in developing functional antiferromagnetic devices.

Here we tried the synthesis of $D0_{19}$ Mn_3X (X = Sn, Ge) thin films by DC-magnetron sputtering for different composition at various temperatures including room temperature. The magnetic transport properties such as anomalous Hall, Nernst effect will be reported.

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P29

Z_2 topological invariant for magnon spin Hall systems

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The classification and characterization of different phases of matter based on the topology of band structures has recently attracted considerable attention. The successful studies on the topological phenomena of electrons have been extended to bosonic systems. However, the topological invariant of bosonic systems with time reversal symmetry has not been identified because Kramers' theorem cannot be directly applied to them.

We introduce the pseudo-time-reversal operator which ensures the existence of ``Kramers pairs" of bosons and define the Z_2 topological invariant for magnon spin Hall systems [1]. The topological invariant is defined by using the Berry connection and curvature which are different from those of electrons [2]. Furthermore, we propose two models of magnon spin Hall systems, kagome- (Figure 1) and honeycomb- (Figure 2) bilayer systems. The second system is the first example of magnon spin Hall systems without spin conservation. We numerically calculate the Z_2 topological invariant of these systems and obtain the results which are consistent with the existence of edge states.

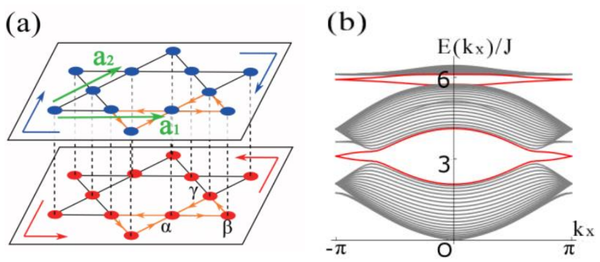

Figure 1: (a) The kagome-bilayer system. (b) Band structure in a strip geometry.

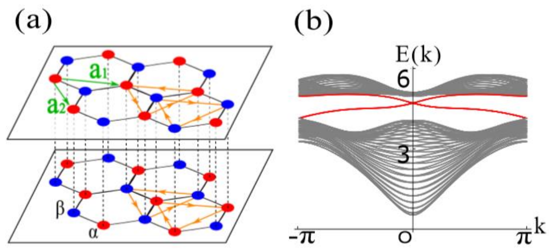

Figure 2: (a) The honeycomb-bilayer system. (b) Band structure in a strip geometry.

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P30

Impact of antiferromagnetic order on Landau level splitting of quasi-two-dimensional Dirac fermions in $EuMnBi_2$

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Dirac fermions in solids have been of current interest for their unique transport properties. The interplay of Dirac fermion with magnetism in magnetic Dirac materials is recently of particular interest. Among them, $EuMnBi_2$ is a rare compound that exhibits quantum transport of Dirac fermions coupled with the field tunable magnetic order[1]. However, it remains elusive how and to what extent the Dirac-like band dispersion is affected.

In this study, we report spin-split Landau levels of quasi-two-dimensional Dirac fermions in $EuMnBi_2$, as revealed by interlayer resistivity measurements in a tilted magnetic field up to ~ 35 T. As shown in Fig. 1, the amplitude of Shubnikov-de Haas (SdH) oscillation in interlayer resistivity is strongly modulated by changing the tilt angle of the field, i.e., the Zeeman-to-cyclotron energy ratio. The effective *g*-factor estimated from the tilt angle, where the SdH oscillation exhibits a phase inversion, differs by approximately 50% between two antiferromagnetic phases. This observation signifies a marked impact of the magnetic order of Eu sublattice on the Dirac-like band structure. The origin may be sought in strong exchange coupling with the local Eu moments, as verified by the first-principles calculation[2].

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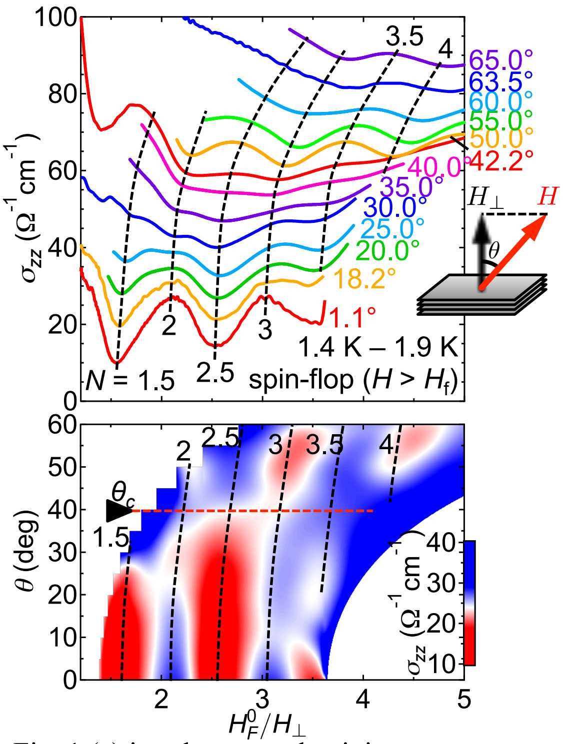

Fig. 1 (a) interlayer conductivity σ_{zz} as a function of $H_F{}^0/H_\perp$, normalized inverse out-of-plane magnetic field. (b) Image plot of σ_{zz}.

P31

Pressure-tuning of the interplay between ferroquadrupole order and superconductivity in $PrTi_2Al_{20}$

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$PrTi_2Al_{20}$ with non-Kramers Γ_3 doublet ground state provides an interesting opportunity to investigate the interplay between the ferroquadrupole order and superconductivity [1,2]. In particular, we previously reported that $PrTi_2Al_{20}$ exhibits the enhancement of superconducting transition temperature near the putative quantum critical point of the ferroquadrupole order at $P_C \sim 11$ GPa, suggesting that quadrupole fluctuations may provide a nonmagnetic glue for Cooper pairing. Another peculiar aspect of $PrTi_2Al_{20}$ is that the non-Fermi liquid (NFL) behavior spans even far away from P_C coinciding with the robust superconducting phase. We found that the NFL state emerges not only under pressure but also in wide magnetic field range, where the resistivity curves are shown to collapse onto a single scaling function, as predicted for the quadrupole Kondo lattice model [3]. In this presentation, we show the complete high-pressure phase diagram of possible quadrupole Kondo lattice system $PrTi_2Al_{20}$ and discuss possible exotic superconductivity in the vicinity of an orbital instability.

[1] A. Sakai *et al.*, J. Phys. Soc. Jpn. **81**, 083702 (2012).
[2] K. Matsubayashi *et al.*, Phys. Rev. Lett. **109**, 187004 (2012).
[3] A. Tsuruta and K. Miyake, J. Phys. Soc. Jpn. **84**, 114714 (2015).

P32

Terahertz anomalous Hall effect in Weyl antiferromagnet Mn_3Sn thin film

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Recently Mn_3Sn has attracted a great deal of attention as a candidate for the Weyl semimetal due to breaking of time reversal symmetry in the non-collinear antiferromagnetic order. One of the most prominent features of this material is that it exhibits giant anomalous Hall effect at room temperature in spite of vanishingly-small net magnetization [1]. In order to discuss intrinsic nature of the anomalous Hall effect originating from large Berry curvature in momentum space, terahertz spectroscopy is important since Mn_3Sn has Weyl points very close to the Fermi energy and therefore peculiar terahertz Hall conductivity may appear as resonant structures due to interband transition across the band-crossing point [2].

Here, we report terahertz time-domain spectroscopy for Mn_3Sn thin films with randomly-oriented magnetic domains. The measurement is performed at zero magnetic field after the samples are fully magnetized under the field of ±5 T. To obtain the optical Hall conductivity $\sigma_{xy}(\omega)$ in the terahertz frequency range, we built up a broadband terahertz polarization-resolved spectroscopy setup between 0.2 to 7 THz (0.8 to 28 meV), and measured the polarization rotation of terahertz electric field in the thin films. Conventional terahertz transmission spectroscopy provides a Drude-like response in the longitudinal optical conductivity $\sigma_{xx}(\omega)$. Then, we also observed the rotation angle ~4 mrad in the 50-nm-thick film and its sign reversal when the opposite magnetic field is applied before the terahertz experiment. The result corresponds to the optical Hall conductivity $\sigma_{xy}(\omega)$~20 $\Omega^{-1}cm^{-1}$ at room temperature, which is consistent with the giant anomalous Hall effect in the DC resistivity measurement. Observation of the terahertz anomalous Hall conductivity in picosecond time resolution will be extended into the study of nonequilibrium dynamics of the Weyl antiferromagnetic system excited by optical pump or intense terahertz electromagnetic excitation.

[1] S. Nakatsuji et al., Nature **527**, 212 (2015).
[2] R. Shimano et al., EPL **95**, 17002 (2011).

P33

Band-tuning-induced giant topological Hall effect in magnetic semimetal α-EuP_3

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Black phosphorus (BP), a material consisting of monoatomic phosphorene layers stacked via van der Waals bonding, is a narrow-gap semiconductor in ambient pressure. It has recently been predicted that BP goes under a topological transition by applying high pressure, resulting in a semimetallic band structure[1].

α-EuP_3 has a crystal structure closely related to BP and contains magnetic Eu^{2+} ions between the P layers (Fig.1). Recent first principle calculations predict that semimetallic band structures originating from the *p*-orbital of phosphorus are realized in α-CaP_3 and α-SrP_3, which are isostructural crystals of α-EuP_3[2]. Therefore, we expect the emergence of non-trivial electronic transport derived from the correlation between magnetism and the semimetallic electronic structure.

So far, we have observed the anomalous Hall effect, which emerges at a certain value of magnetization (Fig.2). This suggests that the magnetically tuned band structure plays an important role. In this poster presentation, I will discuss the correlation between the band's exchange splitting and the electronic transport properties, and also the possibility of a topological origin of the anomaly.

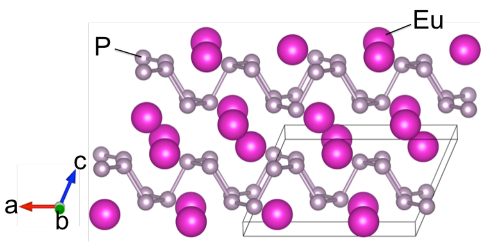

Figure 1: Crystal structure of α-EuP_3.

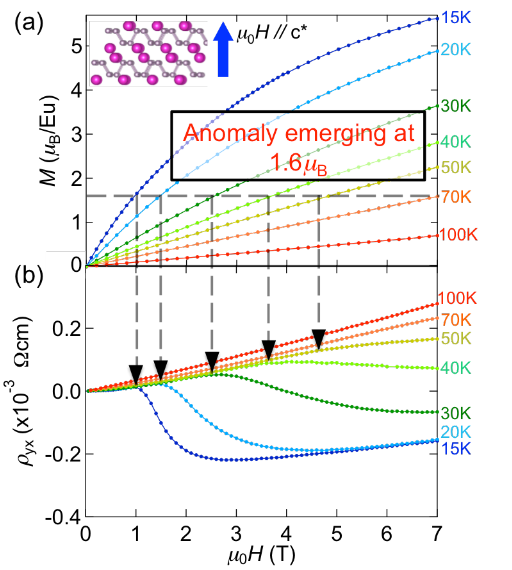

Figure 2: Anomalous Hall effect in α-EuP_3 occuring at a certain value of magnetazation.

[1] Z. J. Xiang, et. al., Phys. Rev. Lett. **115**, 186403 (2015).
[2] Q. Xu, et. al., Phys. Rev. B **95**, 045316 (2017).

P34

Large Topological Responses in the Antiferromagnet Mn_3Ge

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Conventionally, intrinsic anomalous Nernst effect has been investigated in ferromagnets where the transvers voltage drop (Nernst voltage) driven by temperature gradient is proportional to magnetization. However, most recent progress shows that even higher anomalous Nernst voltage can be generated in non-ferromagneic material Mn_3Sn[1], 0.35μV/K and 0.6μV/K, at 300K and 200K, respectively, with a very tiny magnetization, which has been confirmed to come from the Weyl nodes providing large Berry curvature near the Fermi level[2,3].

Compared to Mn_3Sn, Mn_3Ge has the same crystal structure and inverse spin structure [4], but possibly may provide much more Weyl nodes close to the Fermi level because of the smaller spin orbit coupling for Germanium in comparison with Tin[5], and thus might lead to higher anomalous Nernst effect and anomalous Hall effect. For the anomalous Nernst effect in Mn_3Ge, works have not been reported. Here, high quality of Mn_3Ge single crystals are synthesized both by flux and Bridgman method. Our thermoelectric measurements show that the highest anomalous Nernst effect can reache up to 0.45μV/K and 1.3μV/K at room temperature and 100K, respectively, twice higher than the value reported for the antiferromagnet Mn_3Sn. In addition, the obvious negative magneto-resistivity is observed when external magnetic field is applied parallel to the electric current both in and out of Kagome plane configurations, consistent with the existence of Weyl nodes close to the Fermi energy. This makes it an ideal platform for deep understanding of the intrinsic anomalous Hall effect and a good candidate for the high thermoelectric harvesting efficiency device design.

[1] S. Nakatsuji, N. Kiyohara and T. Higo Nature **527**, 212 (2015)
[2] M. Ikhlas, T. Tomita et. al., Nature Physics 13, 1085 (2017).
[3] K. Kuroda and T. Tomita *et al.* Nat. Mater. **16**,1090 (2017)
[4] N. Kiyohara, T. Tomita and S. Nakatsuji Phys. Rev. Appl. **5**, 064009 (2016)
[5] Z. Yang *et al.* Phys. Rev. B. **95**.075128 (2017)

P35

Non-hermitian properties in non-centrosymmetric f-electron materials

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Recently, the physics described by effective non-hermitian Hamiltonian are intensively studied especially in the context of open quantum systems.[1,2] Effective non-hermitian Hamiltonian can be allowed in open quantum systems while the isolated system should be described by hermitian Hamiltonian in the scheme of quantum mechanics.

On the other hand, in strongly correlated systems(SCS), particles have the self-energy which contains finite imaginary part and therefore SCS can be also described by the effective non-hermitian Hamiltonian. Conventionally, the effect of imaginary part of the self-energy was considered just broadening the density of states of the bands. However, last year, Liang Fu's group proposed that this effective non-hermiticity sometimes gives drastic effect.[3] It gives the exceptional points(EPs) where the effective non-hermitian Hamiltonian cannot be diagonalized and the topological number can be defined. Moreover, when there are EPs at the Fermi surface, the bulk Fermi arc emerges between EPs. These non-hermitian effect in SCS has the potential to explain the pseudo-gap in cuprate superconductors and the quantum oscillation in topological Kondo insulator.[4]

In this poster, we show the non-hermitian effect of the self-energy in 2D and 3D non-centrosymmetric f-electron materials by numerical calculation with DMFT/NRG. We use the periodic Anderson model which is one of the minimum model that satisfies the condition for the emergence of the bulk Fermi arc. We proposed that non-centrosymmetric f-electron materials can be one of the good platform for studying non-hermitian effect in SCS. For non-centrosymmetric cases, one of the Kondo gap becomes small due to the spin splitting.[5] Our results shows that when we add the enough anti-symmetric spin-orbit coupling(Rashba SOC in this work) ,for examples by the substitution, the Kondo gaps becomes smaller than the imaginary part of the self-energy and the bulk Fermi arc emerges. Moreover, if we add more RSOC, it splits.[6]

[1] A. Author, B. Second and C. Third, PRX **8**, 031079 (2018).
[2] L. Feng, R. El-Ganainy and L. Ge, http://doi.org/10.1038/s41566-017-0031-1(2018)
[3] H. Shen, B. Zhen and L. Fu, PRL **120**, 146402(2018)
[4] G. Li , *et al*, Science **346**, 1208-1212 (2014)
[5] Suchitra E. Sebastian, et al, Science **349**,287-290 (2015)
[6] YM and R. Peters "Impact of Rashba Spin Orbit Coupling on f-electron materials " soon
[7] YM and R. Peters "Non-hermitian propeties in non-centrosymmetric f-electron materials" coming soon.

P36

Atomic-scale structural and electronic properties of YbB_{12}(001) surfaces

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A Kondo insulator YbB_{12} revives its interest owing to the recent theoretical prediction as a possible candidate for a topological Kondo insulator [1]. The experimental identification of topological surface states, which can explain the resistance plateau of YbB_{12} at low temperatures, is necessary toward understanding of intrinsic electronic properties of strongly correlated topological insulators.

In this work, we use scanning tunneling microscopy (STM) to investigate structural and electronic properties of the YbB_{12}(001) surface on the atomic scale. The flat surface of the YbB_{12}(001) single crystal was prepared by annealing [2] instead of the conventional cleavage. We demonstrate that the quality of the YbB_{12}(001) surface strongly depends on the annealing procedures. Furthermore, atomically-resolved spatial dependences of the differential conductance spectrum near the Fermi energy reveal that the in-gap state emerging inside the Kondo hybridization 4.4 K is a robust surface state against structural variations.

[1] H. Weng *et al.*, Phys. Rev. Lett. **112**, 016403 (2014).
[2] K. Hagiwara *et al.*, Nat. Commun. **7**, 12690 (2016).

P37

Majorana edge magnetization in the Kitaev honeycomb model

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Detecting Majorana fermions has attracted great interests recently in condensed matter physics. One of the promising candidates is the Kitaev honeycomb magnet [1], which is an exactly solvable quantum spin model with Majorana-type excitations. The exact solvability comes from the fact that the model can be mapped to a free Majorana fermion model by using the Jordan-Wigner transformation [2]. Besides, the free Majorana fermion model thus obtained has a weak topological character, namely, it belongs to BDI class in two dimensions. This weak topological character is reflected to the Majorana flat bands at the edges [3]. However, it has not been clarfied how to observe the Majorana edge flat bands in experiments.

In this presentation, we propose an approach to detect the Majorana fermions at the edges by measuring the edge magnetization. By using a standard technique to diagonalize free fermion models, we show that there appears a unidirectional magnetization without any transverse magnetization when applying a sufficiently weak magnetic field [4]. This peculiar behavior of the edge magnetization is expected to be a clue to detect Majorana fermions in experiments.

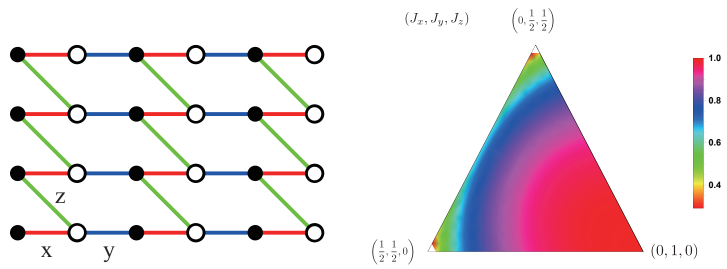

Figure 1: The Kitaev's honeycomb model (left) and the edge magnetization in Ay phase (right).

[1] A. Kitaev, Ann. Phys. **321**, 2 (2006).
[2] X.-Y. Feng, G.-M. Zhang, and T. Xiang, Phys. Rev. Lett. **98**, 087204 (2007).
[3] M. Thakurathi, K. Sengupta, and D. Sen, Phys. Rev. B **89**, 235434 (2014).
[4] T. Mizoguchi and T. Koma, arXiv:1811.10895.

P38

Large anomalous Hall effect in topological insulators with proximitized ferromagnetic insulators

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In magnetically-doped topological insulator thin films, exotic magnetic quantum phases such as the quantum anomalous Hall insulator and axion insulator have been achieved [1,2]. The formation of a mass gap at the Dirac surface state on the topological insulators and the Fermi-level tuning into the gap are both requisite to the emergence of such topological states, being realized not only by magnetic doping but also by proximitizing ferromagnetic insulators. However, the magnitude of electronic responses or the proximity-coupling strength to the surface states remains far smaller than expected.

Here, we report a proximity-driven large anomalous Hall effect in all-telluride heterostructures consisting of a ferromagnetic insulator $Cr_2Ge_2Te_6$ and a topological insulator $(Bi,Sb)_2Te_3$. The anomalous Hall conductance emerges in accord with a ferromagnetic response of the $Cr_2Ge_2Te_6$ layer, while no discernible magnetization is detected in the $(Bi,Sb)_2Te_3$ layer by spin-polarized neutron reflectometry. The results show that the exchange coupling between the surface state of the topological insulator and the proximitized $Cr_2Ge_2Te_6$ layer is effective enough to open the sizeable mass gap in the surface state.

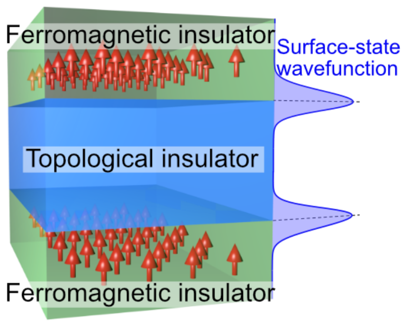

Figure 1: Schematic drawing of proximity coupling between topological insulators and ferromagnetic insulators

[1] C.-Z. Chang *et al.*, Science **340**, 167 (2013).
[2] M. Mogi, M. Kawamura, R. Yoshimi, A. Tsukazaki, Y. Kozuka, N. Shirakawa, K. S. Takahashi, M. Kawasaki and Y. Tokura, Nat. Mater. **16**, 516 (2017).

P39

Topologically Enhanced Anomalous Nernst Effect in Half-Heusler Ferromagnet CoMnSb

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Recently a large anomalous Nernst signal comparable in size to ordinal ferromagnets was found to appear in antiferromagnet Mn_3Sn, showing tiny magnetization [1]. The size of anomalous Nernst effect (ANE) has ever been believed to be proportional to magnetization. This unexpected large ANE was explained by the large fictitious magnetic field in momentum-space (Berry curvature) induced by magnetic Weyl points. A ferromagnetic Weyl material, moreover, is theoretically proposed and experimentally verified in full-Heusler compound Co_2MnGa, where a remarkably high ANE value of 6 μV/K was observed at room temperature [2] as well.

Very recently, large size of Berry curvature was proposed by the first-principle calculation in half-Heusler ferromagnet CoMnSb[3], exhibiting the Nernst coefficient as high as 1.2 μV/K at 300 K. To confirm its Nernst signal size experimentally, we synthesized a single-crystal sample and measured its thermoelectric properties. As a result, we observed a Nernst signal of 0.5 μV/K at 300 K. This size is smaller than the calculated result but expected to be further enhanced by tuning Fermi energy E_F. In addition, transverse thermoelectric conductivity α_{xy} (T) obtained from our experimental results behaved as $-T \log T$ at high temperature as well as observed in Co_2MnGa[2]. This characteristic behavior suggests that the Weyl point exist in the vicinity of E_F in CoMnSb.

[1] M. Ikhlas, T. Tomita *et al.*, *Nature Physics* **13**, 1085 (2017).

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

[3] S. Minami *et al.*, *Applied Physics Letters* **113**, 032403 (2018).

P40

In-plane field and current dependence of the Josephson effect in Nb/InAs/Nb junctions

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Spin-orbit coupling (SOC) is an important ingredient of interesting phenomena such as the spin Hall effect [1] and topological superconductivity [2], in combination with time-reversal symmetry (TRS) breaking perturbation. In-plane magnetic fields applied to 1D or 2D superconducting junctions enable us to access such novel systems because they lift the spin degeneracy with little orbital effects [3]. In this work, we fabricated superconducting junctions with a two-dimensional electron systems (2DESs) in InAs quantum wells, suitable for investigation of superconducting phenomena since they provide good electric contact to the superconductors and Rashba-type strong spin-orbit coupling (SOC) is expected in 2DESs at spatially asymmetric structures of quantum wells.

Two Nb electrodes are attached to a 2DES as shown in Fig. 1 and external magnetic fields were applied along in-plane and out-of-plane directions independently. The junctions exhibit zero-resistance and their critical current I_c oscillates against the out-of-plane field. Without in-plane magnetic fields, this pattern is a well-known Fraunhofer-like pattern, which has a peak at the zero field. However, under in-plane fields, the pattern becomes asymmetric and the maximum I_c decreases. This is attributable to vortex pinning and field modulation due to Meissner effect of the electrodes [3]. In contrast to the in-plane fields, the mesa current reduces the I_c monotonically as shown in Fig. 2. This reduction cannot be explained by either heating or potential shift in the mesa. We are discussing other mechanisms of I_c reduction, for example, spin Hall effect or Zitterbewegung.

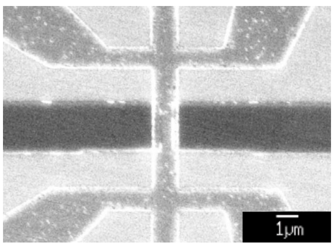

Fig. 1: SEM image of a sample.

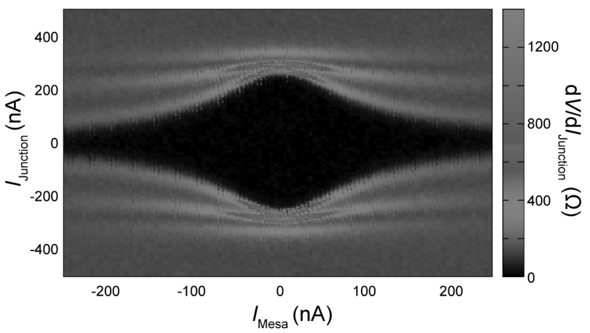

Fig. 2: Differential resistance as a function of Junction current and mesa current.

[1] J. Sinova, *et al.*, Rev. Mod. Phys. **87**, 1213 (2015).
[2] Steven R. Elliott and Marcel Franz, Rev. Mod. Phys. **87**, 137 (2015).
[3] S. Hart et al., Nat. Phys. **13**, 87 (2017), and H. J. Suominen et al., Phys. Rev. B **95**, 035307 (2017).

P41

Non-equilibrium dynamics by field quench in Kitaev model

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Insulating magnets provide a good playground for quantum many-body effects on the spin degree of freedom of electrons in solids. While the spins are usually frozen with magnetic ordering at the lowest temperature, P. W. Anderson suggested that they could remain melting due to strong quantum fluctuations [1], which leads to a new state of matter, the quantum spin liquid (QSL). This state has attracted great interest for a number of decades as it could exhibit topological order and possess fractional excitations with unconventional statistics. Particularly, the Kitaev model has been intensively investigated as its ground state is exactly shown to be a QSL with Majorana excitations fractionalized from quantum spins [2]. Although a lot of attempts have been devoted to the observations of the fractional quasiparticles, the experimental identification remains elusive. This is because the fractional quasiparticles hardly couple with experimental probes.

In this study, to observe the fractional excitations separately, we focus on time evolution of their non-equilibrium dynamics. In our previous work, we examined the magnetic-field effect on the ferro- and antiferro-magnetic Kitaev models using the Hartree-Fock approximation in the Majorana fermion representation [3]. Here, we study the transient magnetic dynamics yielded by the magnetic-field quench by extending the previous work. In the Kitaev model, a quantum spin is fractionalized into low-energy localized Majorana fermions and high-energy itinerant ones. We find that two kinds of Majorana fermions are observed separately in distinct time-scales in the time evolution of the magnetization. On the other hand, this behavior disappears in the forced ferromagnetic phase realized in the high-field case.

[1] P. W. Anderson, Mater. Res. Bull. **8**, 153 (1973).

[2] A. Kitaev, Ann. Phys. (N. Y.) **321**, 2 (2006).

[3] J. Nasu, Y. Kato, Y. Kamiya, and Y. Motome, Phys. Rev. B **98**, 060416(R) (2018).

P42

Quasi-1D bismuth halides exhibiting various topological phases investigated by ARPES

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Topological insulators are a class of materials with metallic surface/edge states due to non-trivial electronic structures in the bulk [1]. After theoretical predictions, various materials have been confirmed to show topologically non-trivial properties through the observing surface/edge states [2,3]. Recently, quasi-one-dimensional (quasi-1D) bismuth halides Bi_4X_4 (X=Br, I) [4] are theoretically predicted to be in the proximity of topological phase transitions [5-7]. However, the determination of their topological phases is difficult only by theoretical calculations, since their band gap sizes and the numbers of band inversions are very sensitive to the computational parameters. Therefore, the direct observation of the band structures by ARPES is necessary to reveal their topological properties. So far, we have experimentally shown that β-Bi_4I_4 is a weak topological insulator with quasi-1D surface states on its side surface, and α-Bi_4I_4 is a trivial insulator due to its bilayer structure [8]. In contrast, experimental study on Bi_4Br_4 has been lacked, despite the prediction that it is a topological crystalline insulator with helical hinge states protected by a C_2 rotation symmetry [7].

In this contribution, we will present our latest ARPES results of Bi_4Br_4. The measured Fermi surface consists of island-like features at the M point of the (001) surface Brillouin zone similarly to the case of α-Bi_4I_4. The band dispersion along k_x axis is faster than α-Bi_4I_4, reflecting the smaller distance between Bi atoms along a-axis. More details of the electronic structure of Bi_4Br_4 will be discussed in the poster.

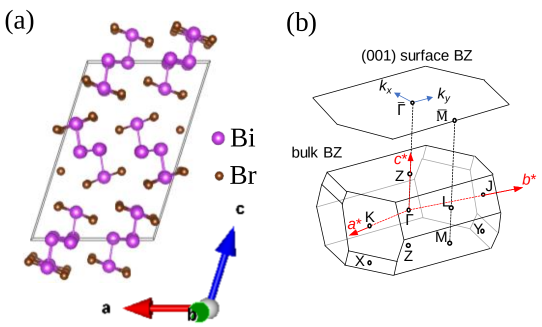

Figure 1: (a) Crystal structure and (b) the bulk and surface projected Brillouin zone of Bi_4Br_4.

[1] L. Fu and C. L. Kane, Phys. Rev. B **76**, 45302 (2007).
[2] Y. Xia *et al.*, Nat. Phys. **5**, 398 (2009).
[3] Y. L. Chen *et al.*, Science **325**, 178 (2009).
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[5] G. Autès *et al.*, Nat. Mater. **15**, 154 (2015).
[6] C.-C. Liu *et al.*, Phys. Rev. Lett. **116**, 66801 (2016).
[7] F. Tang, H. C. Po, A. Vishwanath, and X. Wan, arXiv 1805.07314 (2018).
[8] R. Noguchi *et al.*, Nature, accepted (2018).

P43

Spontaneous Hall effect in a Luttinger semimetal $Pr_2Ir_2O_7$ thin film

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In 5*d* electron systems represented by iridates, spin-orbit and Coulomb interactions are of approximately the same order of magnitude. It has been theoretically predicted that as a result, novel topological phases such as Weyl semimetal and strongly correlated topological insulator states may emerge [1]. We have focused on a pyrochlore iridate, $Pr_2Ir_2O_7$, and found several interesting physical properties [2-5]: it is metallic down to the lowest temperatures but behaves as a spin liquid [2, 3]; it exhibits spontaneous Hall effect generated by spin chirality [4]; and it has a Fermi node formed by quadratic band touching of the doubly degenerate valence and conduction bands at the Γ point at the Fermi level [5]. Moreover, we successfully fabricated (111)-oriented pyrochlore $Pr_2Ir_2O_7$ epitaxial thin films [6, 7]. The spontaneous Hall effect in the thin films appears up to about 50 K which is higher than the bulk report, and it is likely that the Weyl semimetal phase exists in the $Pr_2Ir_2O_7$ thin films.

When we measure the magnetic field dependence of magnetoresistance (MR) at 2 K in the configurations where the magnetic field (B) is either perpendicular ($B \perp I$, B//[110]) or parallel (B//I, B//[$1\bar{1}0$]) to the current, which experimental configurations are crystallographically equivalent, both MR curves show negative MR due to the 2-in-2-out spin configuration. In contrast, the negative MR is larger when the magnetic field is parallel to the current. In the presentation, we will analyze the difference in the MR curves, and discuss the origin of the effect, such as a chiral magnetic effect.

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P44

Numerical study of nonreciprocal spin current in monoaxial chiral magnets

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Chiral magnets often show interesting properties associated with their peculiar spin structures originating from the antisymmetric exchange interaction called the Dzyaloshinkii-Moriya interaction. A typical example is found in a monoaxial chiral magnet $CrNb_3S_6$ [1]. While this compound shows a chiral helimagnetic state at zero magnetic field, it turns into a chiral conical magnetic state in a field parallel to the helical axis (Figure 1). The chiral magnetic structures potentially give rise to nonreciprocal transport phenomena, as they break spatial inversion and time reversal symmetries simultaneously [2]. However, such interesting possibilities have not been fully explored, especially for charge and spin currents.

In the present study, we investigate the spin-dependent transport in the chiral conical magnetic states using a minimal itinerant electron model, a one-dimensional Kondo lattice model. The conductance of spin current is calculated numerically by using a Landauer-type formula based on a Green's function method. We show that the system exhibits nonreciprocal spin transport, which depends on the angle of conical spins, the chirality of the magnetic structures, and the polarized direction of the spin current (Figure 2). We discuss the origin of the nonreciprocity by analyzing the spin states near the edges [3].

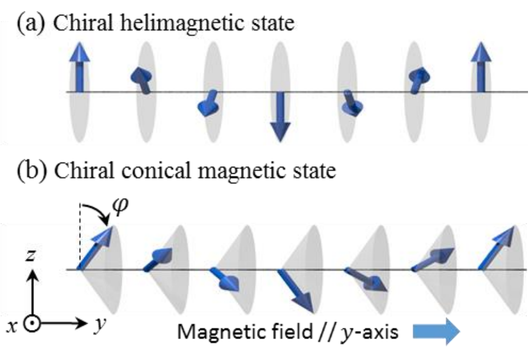

Figure 1: Schematic pictures of (a) a chiral helimagnetic state and (b) a chiral conical magnetic state.

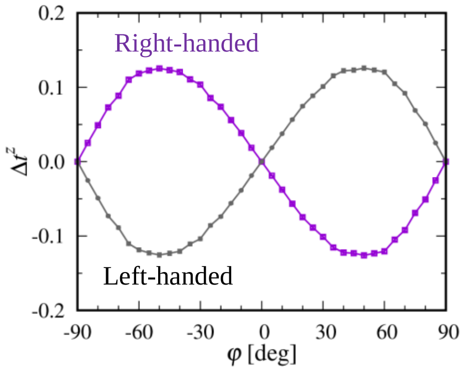

Figure 2: The conical angle φ and chirality dependence of the difference of the transmittances Δt^z between right- and left-going spin current polarized along the z axis.

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P45

Magnetic phase diagram of an orthorhombic Kagomé cobaltite $CaBaCo_4O_7$

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Magnetic frustration often plays an important role in multiferroic properties as is exemplified by the electric polarization induced by the spiral magnetic order. $CaBaCo_4O_7$ is a multiferroic material hosting magnetic frustration[1] exhibiting the largest electric polarization change about 17 mC/m^2 at the ferrimagnetic transition so far among all the multiferroic materials[2]. $CaBaCo_4O_7$ belongs to the space group $Pbn2_1$. Magnetic Co ions form Kagomé- and trianglar- lattice layers, which alternately stack along the *c*-axis.

$CaBaCo_4O_7$ shows a ferrimagnetic transition at $T_c \sim 60$ K at zero magnetic field. The specific heat and the electric permittivity of single crystal $CaBaCo_4O_7$ exhibits another anomaly at $T^* \sim 69$ K slightly higher than T_c in zero mangetic field, while the origin of the anomaly was not clarified[2]. We have measured the magnetization and elastic constants in detail, our present result reveals that paramagnetic-antiferromagnetic transition occurs at T^*. Furthermore, we propose a magnetic phase diagram of $CaBaCo_4O_7$ (Fig. 1) in the B-T plane based on the measurement of elastic constants C_{11}, C_{55}, C_{66}. The transition magnetic field was determined by a measurement of the magnetization of detwinned sample.

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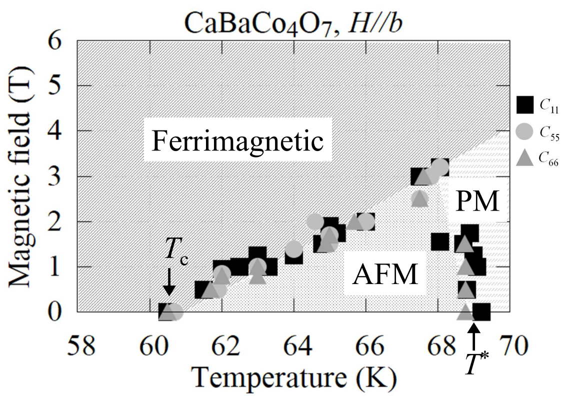

Figure 1: Magnetic phase diagram of $CaBaCo_4O_7$ for the magnetic field parallel to the *b* axis.

P46

Supercurrent on accumulation edges of an InAs quantum well

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Though a superconductor has an energy gap opening at the Fermi level, the Andreev reflection mechanism (ARM) connects metallic states and condensate of Cooper pairs adiabatically [1] at the metal-superconductor interface. Here strong interest exists in the case we replace the metal with an insulator with non-trivial topology like a quantum Hall insulator (QHI). Some theories predict the conductive states at the quantum Hall edge are connected to the condensate adiabatically via the ARM. In such a situation a single edge state works both as an electron and a hole conduction channel, hence bears double of the quantum conductance $2G_q$ (G_q=$2e^2/h$). Connecting one edge to a normal electrode disturbs creation of hole edge channels, enabling study of the other edge exclusively.

We fabricated NbTi/2-dimensional electron gas (2DEG)/NbTi junctions from an InAs quantum well with inverted modulation doping (The mobility and the concentration are 1.66×10^4 cm^2/Vs and 2.11×10^{12}cm^{-2}, respectively). On one edge, a trench-type quantum point contact was fabricated (Fig. (a)). With increasing the negative gate voltage, the critical current was strongly reduced (Fig. (b)), while the period of the interference pattern was kept constant (Fig. (c) and (d)). The latter result means that the gate voltage gives little change in the area for the supercurrent to flow. We hence infer that edge channels are formed by charge accumulation and they sustain large amount of supercurrent, which are depleted by applying negative gate voltage.

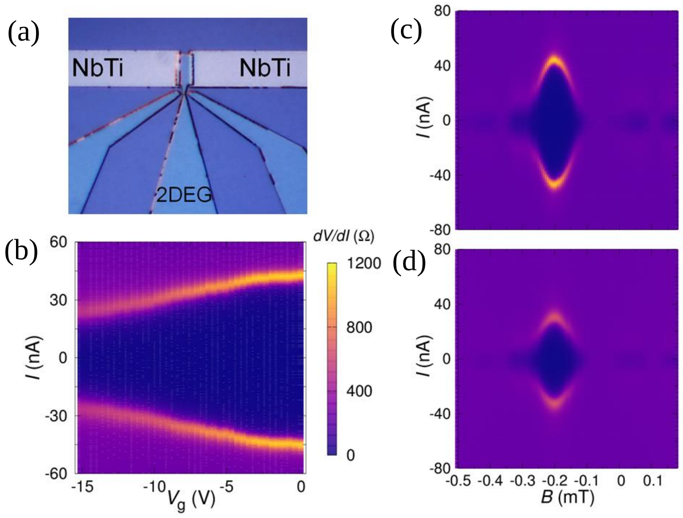

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Figure: (a) Optical micrograph of the sample. (b) Color plot of d*V*/d*I*. (c) Magnetic interferance pattern d*V*/d*I* with gate voltage 0 V and (d) -12 V, respectively.

P47

Symmetry Indicators for Topological Superconductors

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Many people are making efforts to investigate the relationships between topology and symmetry, especially searching for topological crystalline insulators (TCI) and topological superconductors (TSC). L. Fu and C. L. Kane proposed the first efficient way to discover TI, called Fu-Kane formula [1], which is applicable to inversion symmetric systems. Recently, there have been fundamental advances in the method of symmetry indicators [2] and in a similar formalism, which provide an efficient way to diagnose the topology of band insulators and semimetals based on the representations of valence bands at high-symmetry momenta. This scheme can be understood as a generalization of the Fu-Kane formula that computes the topological index in terms of inversion parities to arbitrary space groups and a wider class of topologies including higher-order ones. It formed the basis of recent extensive material searches based on the density functional theory (DFT) calculation by several groups that resulted in the discovery of an enormous number of new topological materials [3-5]. Up to this moment, however, symmetry indicators are applicable only to insulators and semimetals in which a fixed number of valence bands exist below the Fermi level at every high-symmetry momentum. If one wants to apply this method to SCs, one must examine the representations in the band structure of the Bogoliubov-de Gennes (BdG) Hamiltonian including a gap function. In fact, this is the approach taken in Ref. [6] that recently extended the symmetry indicators to the 10 Altland-Zirnbauer symmetry classes. However, this is not ideal because such a band structure is not available in the standard DFT calculation. Furthermore, in this way, the total number of bands that have to be taken into account can be huge unless one uses an effective tight-binding model.

In this work, we further develop the theory of symmetry indicators exclusively designed for SCs. It enables us to determine the topology of SCs based on the representations of a finite number of bands below the Fermi surface in the normal phase, although one still has to assume a symmetry transformation property of the gap function [7].

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P48

Quantum oscillations in topological Kondo insulator

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One of the most puzzling recent experimental discoveries in condensed matter physics has been the observation of quantum oscillations in insulating materials SmB6 and YbB12 [1,2]. Our understanding of quantum oscillations is rooted in the existence of a Fermi surface; electron bands, which form the Fermi surface, form Landau levels in a magnetic field. When the magnetic field strength is changed, the energy of these Landau levels changes which lead to an oscillatory behavior in almost all of the observable properties. However, SmB6 and YbB12 are strongly correlated f electron systems for which a gap develops due to a hybridization between conduction electrons and strongly correlated f electrons, and thus a large resistivity at low temperatures can be measured. Thus, we can expect that SmB6 and YbB12 do not possess a Fermi surface, thus there are no electrons, which can form Landau levels, close to the Fermi energy. On the other hand, SmB6 and YbB12 are both good candidates for topological Kondo insulator. Naturally, the question arises, if these quantum oscillations can be due to the interplay between non-trivial topology and strong correlations.

We here answer this question by showing results of dynamical mean field theory in a magnetic field for a two dimensional topological Kondo insulator. We demonstrate that the gap closing, described for a noninteracting continuum model with momentum dependent hybridization [3], persists for a topological Kondo insulator on a two dimensional (2D) lattice. Furthermore, we demonstrate that the amplitude of quantum oscillations is strongly enhanced due to correlations, which makes them easily observable in quantities like magnetization and resistivity over a wide range of magnetic fields before the magnetic breakdown occurs.

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P49

Spin to charge conversion via magnon-phonon coupling

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We demonstrate a spin to charge current conversion via magnon-phonon coupling and an inverse Edelstein effect on the hybrid device Ni/Cu(Ag)/Bi_2O_3. The generation of spin current ($J_s \approx 10^8$ A/m^2) due to magnon-phonon coupling reveals the viability of acoustic spin pumping as a mechanism for the development of spintronic devices. A full in-plane magnetic field angle dependence of the power absorption and a combination of longitudinal and transverse voltage detection reveals the symmetric and asymmetric components of the inverse Edelstein effect voltage induced by Rayleigh-type surface acoustic waves. While the symmetric components are well studied, asymmetric components still need to be explored. We assign the asymmetric contributions to the interference between longitudinal and shear waves and an anisotropic charge distribution in our hybrid device.

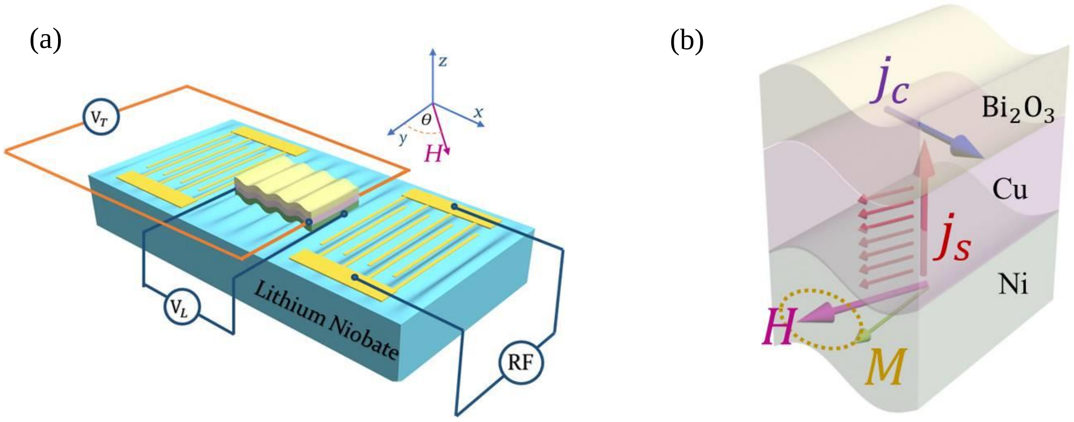

Figure 1. Schematic representation of acoustic spin pumping device in our study **(a)**, and schematic of spin to charge conversion mechanism induced by magnon – phonon coupling **(b)**.

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Research highlights RIKEN

P50

Spin-dependent diode performance in fully epitaxial magnetic tunnel junctions with rock-salt type ZnO/MgO bilayer tunnel barrier

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Metal/insulator/metal (MIM) and metal/insulator/insulator/metal (MIIM) tunnel diodes have great potential for high-frequency rectifier systems, such as for THz/infrared detectors and radio-frequency energy harvesting applications [1,2]. Amorphous or polycrystalline tunnel barriers have often been used in both MIM and MIIM diodes, and a single-crystalline tunnel barrier has never been used despite its high potential for tunnel-device applications. Here, we report on the spin-dependent diode properties of fully epitaxial Fe/ZnO/MgO/Fe(001) magnetic tunnel junctions (MTJs) with a MIIM structure, in which ZnO has a metastable rock-salt crystal structure. Note that, for these MTJs, the operation principle of the rectifying process does not come from a spin-torque diode effect [3] but from intrinsic nonlinear and/or asymmetric current-voltage (*I-V*) characteristics.

MTJ films were prepared by molecular beam epitaxy. The structure of the MTJ was Au (5 nm) / Co (10 nm) / Fe (5 nm) / ZnO (1.2 nm) / MgO (1 nm) / Fe (30 nm) /MgO(001) substrates. Crystallographic studies, such as RHEED and TEM observations, revealed that the ZnO tunnel barriers are single-crystalline with a rock-salt crystal structure. Magnetoresistance ratios up to 96% (127%) were observed at RT (20 K).

We found that the MTJs exhibited notable asymmetric *I-V* characteristics due to the bilayer tunnel barrier, and those diode properties strongly depended on the magnetization alignment of the Fe electrodes. The current responsibilities of the MTJs were largely enhanced at the anti-parallel alignment (2 ~ 3 A/W at RT) and almost comparable to those of high-performance MIIM diodes with dissimilar electrodes [4] as well as to a state-of-the-art spin-torque diode [2,5]. We demonstrated that a zero-bias anomaly in the tunnel conductance, which originates from the magnon excitations at the Fe/barrier interfaces, plays a crucial role in observed spin-dependent diode performance.

This work was supported by the Grant-in-Aid for Scientific Research on Innovative Area, “Nano Spin Conversion Science” (Grant °No. 26103003).

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P51

Giant anomalous Nernst effect at room temperature in Co_2MnGa

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T. Koretsune[2,4], M.-T. Suzuki[2,4], N. Takemori[4], R. Ishii[1], D. N.-Hamane[1], R. Arita[2,4],
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Thermoelectric generation based on the Seebeck effect have been studied intensively to overcome the energy problem. On the other hand, metallic ferromagnets show the electric voltage perpendicular to both magnetization and an applied temperature gradient, so called the anomalous Nernst effect (ANE). This transverse geometry enables a lateral configuration of the thermoelectric modules to efficiently cover a heat source compared to the conventional Peltier device [1]. However, the size of ANE is too small for practical applications.

Recent theoretical and experimental investigations on topological material have indicated that the intense Berry curvature of Weyl points near the Fermi energy can potentially enhance the intrinsic ANE [2-4]. Thus, there must be some materials which can show large ANE in such Weyl magnets.

Here, we report the giant ANE in the full-Heusler ferromagnet Co_2MnGa, reaching a record high value S_{yx} ~6 μV/K at room temperature [5]. The crossover from Mott relation $\alpha_{yx} \sim T$ to $-\ln T$ dependence is observed on warming, indicating the proximity to the quantum Lifshitz transition between type-I and type-II magnetic Weyl fermions.

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P52

Chirality inversion and thermal Hall effect in Weyl superconducting state of URu_2Si_2

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In URu_2Si_2, U atoms form body centred tetragonal structure with anisotropy in the c-axis direction and have sublattice degree of freedom. Below approximately 0.75GPa and 1.4K, it is found that chiral d-wave superconductivity is realized. Moreover, below approximately 17.5K, so-called hidden ordered phase is realized. The Fermi surface exists around the M points in k space, and there are point nodes at the north and south poles of the Fermi surface and horizontal line node at the surface of $k_z = 0$ [1, 2]. These point nodes are weyl nodes, which are protected by topological number [3, 4]. The Chern numbers, which are defined on 2D surface, of Weyl superconductors when the $k_x - k_y$ surface crosses Weyl nodes. The order parameter of URu_2Si_2 in hidden ordered phase has not been uncovered. Hence, the hidden order parameter of URu_2Si_2 has been investigated. Furthermore, the topological of chiral d-wave superconducting state of URu_2Si_2 has not been fully understood. Therefore, we examined the topological properties by calculating the Chern number, energy spectrum and thermal Hall conductivity. For various magnitudes of the ratio of the inter-sublattice pairing and intra-sublattice pairing, we clarified topological properties. We found chirality inversion, which means the sign change of Chern numbers. These changes of Chern numbers indicate appearance of a new kind of Weyl points. Moreover, when the influences of the hidden order are considered Fermi surface is deformed and odd Chern number −1 or 3 is found. Hence, we conclude that hidden ordered phase changes the configuration of Weyl points.

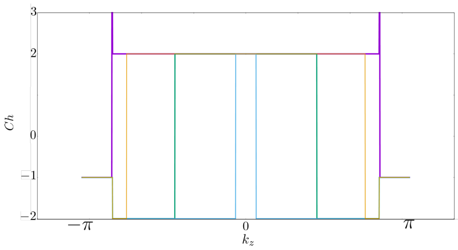

Figure 1: Relation between k_z and Chern number. Influences of the hidden order are considered. There are some points where the Chern number changes. These changes imply that the Weyl nodes exist there.

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P53

Spin current correlation in a three terminal quantum dot

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Observation of current correlations in nano-size conductor elements has brought a rich physics. For example, shot noise tells us an effective charge of current-carrying particle, and a current cross correlation between paths and spin current cross correlations reflect statistics and entanglement of the current-carrying particle, respectively[1-3].

We study current cross correlations in a quantum dot connected to more than three electric lead electrodes in the Kondo regime and the regime with zero electron in the dot. Especially we investigate cross correlation of linear and nonlinear spin currents through different electric lead electrodes and discuss properties of the Bell-state entanglement that emerges between lead electrodes.

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P54

Observation of magnetically combined two-dimensional electronic states in a layered antiferromagnet $EuSn_2As_2$

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[3]*Department of Physics, The University of Tokyo, Japan*
[4]*Diamond Light Source, UK*

Recently, the layered material, which is composed of layered two-dimensional materials by van der Waals force, attracts attention by the standpoint from the developing of the novel functionally materials. In this system, we can configure and control the electronic property, optical property, and spin orbit coupling by choosing the properties of each layers. From this standpoint, we study $EuSn_2As_2$, which is composed ferromagnetic two-dimensional Eu layer and double SnAs layer.

In $EuSn_2As_2$, the Eu spins are coupled antiferromagnetically across adjacent layers, and the Neel temperature is ~25 K. From the transport measurement, the increasing in the resistivity of $EuSn_2As_2$ below Neel temperature is observed. The angle resolved photoemission spectroscopy measurement shows the three-dimensional band dispersion above Neel temperature around Γ point. This band dispersion changes to two-dimensional below Neel temperature, and the transition of the Fermi surface is occurred. The first-principle calculation well reproduces this transition of the electronic states. This result shows that the magnetic ordering of the Eu spins modifies the dimension of the electronic system and affects the transport property. Our findings suggest that the magnetic ordering affects the band engineering via developing of the layered materials, opening the possibility of tailoring magnetoresistance by appropriate structural electronic engineering.

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P55

Surface acoustic wave on natural and artificial multiferroics.

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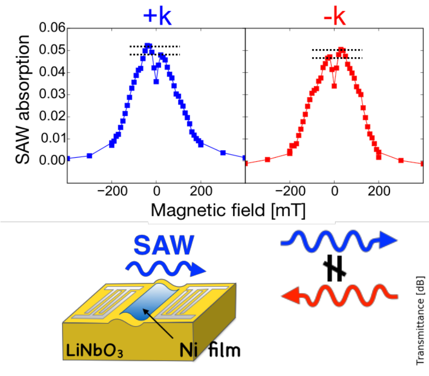
[3]*Department of Applied Physics, Stanford University,*
[4]*National Institute of Advanced Industrial Science and Technology*

Surface acoustic waves (SAWs) are an acoustic wave mode propagating on the surface of the medium. On piezoelectric materials, the SAW can be electrically excited and detected with use of interdigital transducers (IDT), which consists of two interlocking comb-shaped electrodes. The devices composed of two IDTs on the piezoelectric substrate are widely used as bandpass filters in many electronic devices such as cellphones.

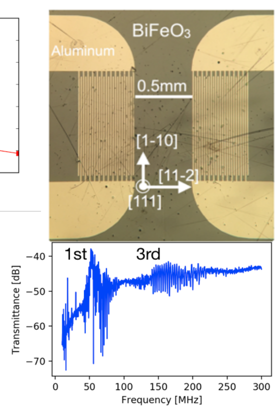
Multiferroics are a class of materials, in which ferroelectricity and magnetism coexist. The strong electromagnetic coupling in multiferroics gives rise to novel phenomena such as nonreciprocal directional dichroism. When the substrate of SAW devices is replaced by multiferroic materials, interesting magnetoelectric responses are expected.

Here we investigated SAW propagation on artificial and natural multiferroics.

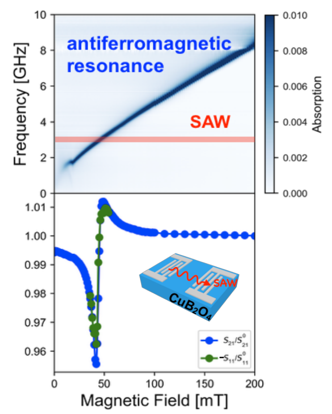
We have found that the SAW signals are largely modulated by magnetic fields for these materials. In ferromagnetic/piezoelectric hybrid device Ni/$LiNbO_3$, which can be viewed as the artificial multiferroics, we observed nonreciprocal propagation of SAW: the absorption and phase velocity are dependent on the sign of the wave vector [1]. In multiferroic materials $BiFeO_3$ and CuB_2O_4, piezoelectricity and magnetic order coexist. We successfully excited SAW by utilizing piezoelectricity of $BiFeO_3$ and observed the intensity and the velocity modulation by the magnetic field [2]. In the CuB_2O_4 SAW device, we observed SAW propagation coupled to antiferromagnetic resonance[3].



Nonreciprocal SAW propagation [1]



First SAW excitation on Multiferroics [2]



SAW coupled to Antiferromagnetic resonance [3]

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P56

Control of electron spin through quantum Hall edge-spin entanglement

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The electron correlation effect brings about spin-separation of the quantum Hall states (quantum Hall ferromagnets). In such situation, the kinetic motion (edge state) and the spin have maximal entanglement through which the spin can be manipulated. However, only a limited number of experiments have been reported on that due to the difficulty in introducing non-adiabatic inter-edge transition[1][2]. Here we demonstrate that electron filling factor and spatial shaping of edges strongly affect the controllability of spins.

The sample configuration is shown in Fig.1. Five Au/Ti gates were fabricated onto an edge of a two-dimensional electron system (2DES) in an AlGaAs/GaAs heterostructure with the mobility of 90 m^2/Vs. We cooled the sample down to 30 mK and applied perpendicular magnetic field B up to 9 T, at which the 2DES is in the quantum Hall state with the filling of $\nu = 2$. Under the Gate L and R, the electron concentration was reduced to $\nu_L, \nu_R = 1$ for separation of the spin-polarized edge states. One edge state which goes through the $\nu_R = 1$ region meets the others at the lower right corner of Gate SR. At a sharp corner in the electron orbit, the Landau-Zener tunneling brings about non-adiabatic inter-edge channel transition for some portion of electron wavefunction and the electron spin starts precession alongside Gate C. The spin state at the left corner of Gate SL is measured by current distribution ratio $D = I_L/(I_L + I_B)$. Fig.2 shows B and Gate C voltage dependence of D, which shows oscillation in both direction of the axis. This means that we controlled spin precession with Gate C voltage.

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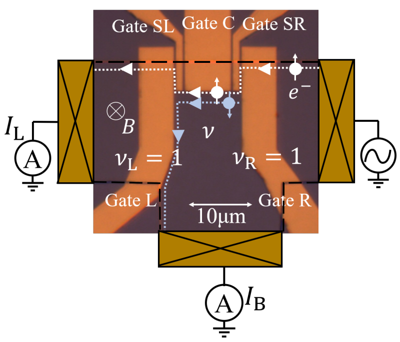

Figure 1: Optical micrograph of the sample and terminal configuration.

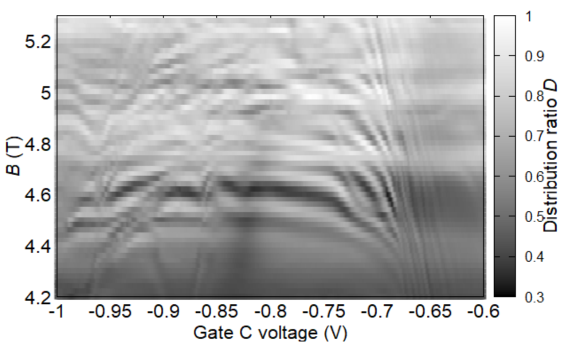

Figure 2: Gate C voltage and magnetic field dependence of current distribution $D = I_L/(I_L + I_B)$.

P57

Quadrupolar Kondo Effect in Magnetoresistance of Non-magnetic Γ_3 System PrV_2Al_{20}

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$PrTr_2Al_{20}$ (*Tr*: Ti,V) is known to be one of the first example of quadrupole Kondo lattice system; namely, the crystalline electric field ground state is the nonmagnetic cubic Γ_3 ground doublet and clear *c*-*f* hybridization is observed [1-3] Nonmagnetic order is observed at T_Q = 2.0 K (Ti) and 0.75 K, 0.65 K (V) due to the ferro- and antiferro- quadrupole order, respectively. [1, 2, 4] In addition, superconductivity is observed at Tc = 0.2 K (Ti) and 0.05 K (V) [4, 5], and heavy fermion superconductivity with the enhanced T_c = 1 K (Ti) is found under the hydrostatic pressure of 8 GPa. [6] Comparing PrV_2Al_{20} with $PrTi_2Al_{20}$, PrV_2Al_{20} shows much stronger *c*-*f* hybridization effect. Indeed, PrV_2Al_{20} exhibits anomalous metallic behavior in resistivity $\rho \sim \sqrt{T}$, magnetic susceptibility $\chi \sim -\sqrt{T}$, and specific heat $C \sim T^{-1/2}$, while $PrTi_2Al_{20}$ exhibits ordinary Fermi liquid behavior. [1] Although the origin of this anomalous metallic behavior in PrV_2Al_{20} is most likely due to the quadrupole Kondo effect, there is still lack of clear evidence.

Here, we report the magnetic and quadrupole Kondo effect in PrV_2Al_{20} based on the magnetoresistance, magnetic susceptibility and specific heat measurement, and discuss the origin of the anomalous metallic behaviors of PrV_2Al_{20}.

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P58

Theory of proximity effect in Rashba nanowire junction

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Superconductiong proximity effect is a phenomenon in which Cooper pairs penetrate into N (normal metal) at N / S (superconductor) junction. Then, local density of states (LDOS) in N has a gap like structure around zero energy. At DN (diffusive normal metal) / S (spin-triplet) junction, however, LDOS in DN has a zero energy peak (ZEP) and a zero bias conductance peak (ZBCP) is quantized. The phenomenon is anomalous proximity effect.

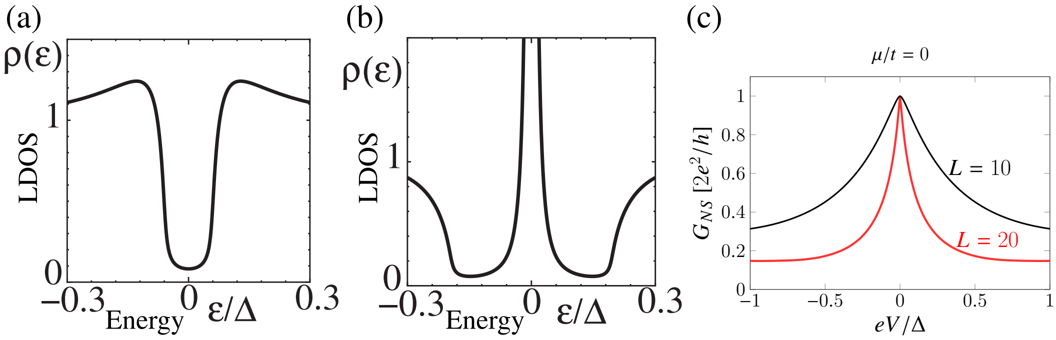

Figure 1: While LDOS has a gap like structure in conventional proximity effect (Fig .1(a)), there is a ZEP of LDOS in anomalous proximity effect (Fig. 1(b))[1]. Behavior of a quantized zero bias conductance (Fig. 1(c))[2].

The zero energy states in anomalous proximity effect is Majorana fermion. It is a quasiparticle of which creation and annihilation are identical. The application of it is quantum computation. It is revealed that Majorana fermion accompanies odd-frequency pairing[3].

Kitaev chain is a one-dementional spinless p_x-wave superconductor. However, it has not been achieved yet. The model which is more realistic than Kitaev chain is a nanowire with Rashba spin-orbit coupling and Zeeman field proximately coupled to a spin-singlet s-wave superconductor (Rashba nanowire system). It is effectively equivalent to Kitaev chain at low energy.

Although proximity effct at Rashba nanowire junction is calculated with Recursive Green's funciton[3], the spacial dependence and symmetry of Cooper pairs is not revealed yet. In this talk, we discuss the change of the spacial dependence and symmetry of Cooper pairs from the topological regime to the non-topological regime by tuning chemical potential.

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P59

Fabrication and Evaluation of Magnetic Topological Insulator Heterostructure $MnTe/(Bi_{1-x}Sb_x)_2Te_3$

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Inducing magnetism into topological insulators (TIs) causes intriguing exotic phenomena such as the quantum anomalous Hall effect (QAHE), which is promising for spintronics due to the dissipation-less edge current. To realize QAHE, it is necessary to open a gap in the surface-band, Dirac cone, and tune the Fermi level (E_F) within the gap. A lot of reported studies have focused on doping magnetic impurities into TI to open the gap. However, due to obstacles such as magnetic scattering or inhomogeneous magnetism, the QAHE has been observed still only at very low temperature (10 - 100 mK).

Previously, we reported Bi_2Se_3 including a self-assembled ferromagnetic Mn single layer on a Si(111) substrate by MBE , and confirmed the gap opening [1]. However, E_F was not located in the gap so that it was difficult to observe the QAHE. On the other hand, it is known that E_F in $(Bi_{1-x}Sb_x)_2Te_3$ can be tuned to be both n and p types by changing the concentration x [2]. In this study, we have grown $MnTe/(Bi_{1-x}Sb_x)_2Te_3$ (MnTe/BST) and aimed to fabricate a high-quality topological magnetic heterostructure and to tune E_F within the gap. Because depositing MnTe induces holes, which was confirmed by the Hall effect also, we planned to tune E_F of BST toward the conduction band side initially as shown in Fig. 1(a), then expected E_F to lie at the Dirac point after deposition of MnTe. The resultant optimized $x = 0.89$, and the ARPES image of the band dispersion shows that the Dirac point is just the same energy as E_F as shown in Fig. 1(b) and the inset. Additional and more detailed data containing magnetic and transport measurements will be shown in my presentation.

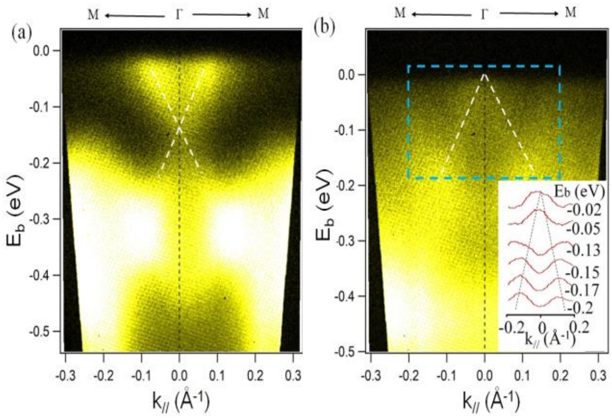

Figure 1. *E-k* dispersion images by ARPES of (a) $(Bi_{0.11}Sb_{0.89})_2Te_3$ and (b) $MnTe/(Bi_{0.11}Sb_{0.89})_2Te_3$ at 77 K. The inset of (b) shows momentum-distribution curves (MDCs) at the respective energy ranges near E_F represented by the blue dashed square.

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P60

Pressure induced phase transition on a frustrated square lattice spin system $RbMoOPO_4Cl$

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For past a few decades, great efforts have been devoted to search nontrivial quantum disordered states in the magnetically frustrated systems[1]. Geometrically frustrated magnets with triangular or Kagome lattices are one of the target materials. Since the competition of the equivalent exchange interactions arises the frustration, perfectness is required in the lattice geometry to realize the disordered phases. This point prevents us to find out the disordered phases. Another type frustration appears in the competition between inequivalent exchange interactions, such as the nearest neighbor J_1 and the next nearest neighbor J_2 exchange interactions. The disordered phases in these systems seem more favorable to tolerate the structural distortions, since relatively wide values of J_2/J_1 preserve strong magnetic frustrations.

Frustrated square lattice magnets are one of such systems, where three ordered phases, Columnar-type (CAF) and Neel-type (NAF) antiferromagnetic and ferromagnetic (FM) ones could be realized as a result of competition of the exchange interactions J_1 running along the side of the square and J_2 running to the diagonal[2,3]. At the intermediate region between the CAF and NAF phases around J_2/J_1~ 0.5, the long range order would be suppressed and spin liquid phase is expected to appear. Although several vanadium and molybdenium compounds have been synthesized[2,3], all materials investigated so far exhibit antiferromagnetic orders with NAF or CAF type spin alignments at ambient pressure.

In this study, we demonstrate the pressure effect on magnetism of a spin-1/2 frustrated square lattice magnet $RbMoOPO_4Cl$, which undergoes the CAF type antiferromagnetic transition at ~T_N=8 K at ambient pressure[4]. Application of hydrostatic pressure controls the strength of magnetic exchange interactions, resulting in a pressure induced phase transition from the CAF spin alignment at ambient pressure to the NAF one above ~3.5 GPa. The structural distortion in $MoOPO_4$ layer would play an important role for tuning the exchange interactions. At the phase boundary there is intermediate region of phase coexistence between the CAF and NAF phases, which implies that the phase transition is a first order transition. The absence of disordered phase in this material may be associated with the exchange anisotropy which destabilizes the spin liquid phase[5].

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P61

Observation of collective phonon mode in quantum spin-orbital liquid $Ba_3CuSb_2O_9$ using time-resolved resonant soft x-ray scattering

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$Ba_3CuSb_2O_9$ is a candidate for quantum spin-orbital liquid [1-3]. Although the octrahedral Cu site is expected to be 2+(d^9, s=1/2), the hexagonal $Ba_3CuSb_2O_9$ does not show any static Jahn-Teller distortion or orbital order as well as the spin order at the lowest temperature (<20 mK) owing to the geometrical frustration. On the other hand, orthorhombic $Ba_3Cu_{1-x}Sb_{2+x}O_9$ shows an orbital and spin order below 200 K. We studied photo-induced dynamics on the Cu sites of $Ba_3CuSb_2O_9$ by means of time-resolved resonant soft x-ray scattering (Tr-RSXS) at the Cu L_3 absorption edge. Tr-RSXS were measured using a Tr-RSXS and XAS system at the BL07LSU of SPring-8 which were developed by us recently [4].

Figure 1 shows time evolution of the Tr-RSXS intensity Q=(002) at the Cu L_3 edge (hv=930.2 eV). The intensity of RSXS reflects the Jahn-Teller fluctuation (or diffusive state) of the Cu 3d electronic state at the low temperature. A coherent oscillation ~165 ps is observed on the photo-induced dynamics for hexagonal $Ba_3CuSb_2O_9$, which is similar to a characteristic frequency observed on the ESR experiment below 40 K [5]. On the other hand, the orthorhombic $Ba_3Cu_{1-x}Sb_{2+x}O_9$ does not exhibit the distinct oscillation. Namely, this slow and long-lived coherent oscillation will correspond to the characteristic frequency or 'collective phonon mode' of the spin-orbital fluctuation in the Cu sites of $Ba_3CuSb_2O_9$.

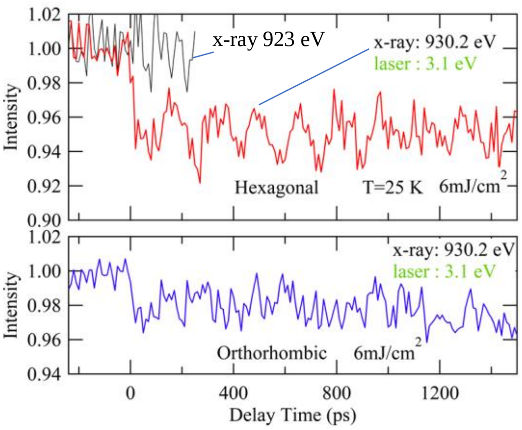

Figure 1: Time-evolution of Tr-RSXS intensity Q=(002) for hexagonl $Ba_3CuSb_2O_9$ (upper) and orthorhombic $Ba_3Cu_{1-x}Sb_{2+x}O_9$ (lower).

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P62

Realization of spin nematic phases in antiferromagnetic dimer dumbbell models on two-dimensional lattices

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Dimer dumbbell arrangement of spins has offered a variety of quantum phases, such as the observation of magnon crystallization in $Ba_2CoSi_2O_6Cl_2$ [1], and the experimental proposal of a quantum spin liquid state in $Ba_3ZnRu_2O_9$ [2]. We have recently proposed that on a triangular lattice consisting of dimer dumbbells constructed by two spin-1/2 interacting antiferromagnetically, ring-exchange or four-spin exchange interactions across two dimers trigger spin nematic orders in the vicinity of an ordinary dimer singlet phase [3]. When triplet dimers are efficiently doped and occupy the adjacent two dimers, the ring-exchange interactions among four spin-1/2 (two triplets) work as spin-1 biquadratic interactions between them. Such interactions are obtained by fourth-order perturbation processes in Mott insulators, and could take a reasonably large value [4].

In usual spin models, the phases of spin-1/2 and spin-1 systems are completely different. However, by replacing the spin-1/2 pairs of dumbbells with spin-1 pairs, we show that the system can be mapped onto a similar model to the spin-1/2 system in certain cases (Fig. 1). Although the ground state should again be a singlet phase, there would be other exchange interactions as the aforementioned spin-1/2 case. We will discuss the relation between these interactions and the feasibility of spin nematic phases in spin-1 dimer systems.

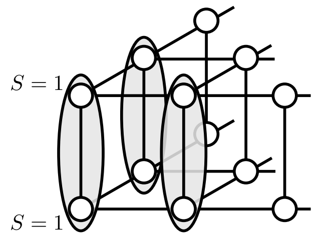

Fig. 1: A schematic image of spin-1 dimer dumbbell models on a two-dimensional lattice.

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P63

Metamagnetism, Criticality and Dynamics in the Quantum Spin Ice $Pr_2Zr_2O_7$

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Geometrical frustration may prevent the formation of long-range magnetic order, giving rise to a diverse range of novel ground states. One of such an unusual state is called quantum spin liquid (QSL) possibly realized in quantum spin ice systems. Its excitations behave like charged particles interacting with linearly dispersive "photon", protected by hidden topological order parameter. Yet, the properties of quantum phase transition between such topological phases remain unknown and are waiting to be established.

Pr-based pyrochlore compounds such as $Pr_2Ir_2O_7$ and $Pr_2Zr_2O_7$ are known to be quantum spin ice systems. $Pr_2Ir_2O_7$ is a fascinating material exhibiting various exotic phenomena such as the spontaneous anomalous Hall effect [1]. In contrast to $Pr_2Ir_2O_7$, the insulating $Pr_2Zr_2O_7$ renders a simplified platform to explore the physics of quantum spin ice. K. Kimura *et al*. [2] reported the absence of "pinch points" in the inelastic neutron scattering spectrum of $Pr_2Zr_2O_7$, suggesting the breakdown of the ice rule owing to quantum fluctuations — a promising hint of a U(1) QSL state. In a recent study [3], it was found that structural disorder acts as a transverse field on the non-Kramers Pr^{3+} ion in $Pr_2Zr_2O_7$, stabilizing the QSL state. Under a magnetic field along the [111] axis, classical spin ice materials undergo a first-order metamagnetic transition [4]. Although theoretical studies [5] predict the existence of metamagnetic transition in quantum spin ice, a comprehensive experimental investigation is still lacking. Here, we report magnetization, thermal expansion, and magnetostriction measurements on $Pr_2Zr_2O_7$. These measurements aim to clarify the nature of the metamagnetic transition and to probe possible topological quantum criticality.

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P64

Superconductivity near a ferroelectric quantum critical point in La-doped $SrTiO_3$

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In this paper, we report an increase of the superconducting transition temperature T_C upon the oxygen isotope (^{18}O) substitution for La-doped $SrTiO_3$ single crystals prepared by floating zone method. Figure 1 shows the resistive transitions [(a), (b)] and the evolution of the critical temperature T_C (c) for the normal and enriched $Sr_{1-x}La_xTi(^{16}O_{1-z}{}^{18}O_z)_3$ crystals. In Fig. 1(a) and 1(b), T_C increases upon the substitution of normal oxygen with the ^{18}O, and it exceeds 500 mK for the crystal with x = 0.0035 and z = 0.57 (b). In the insulating $SrTiO_3$, the quantum paraelectric state is changed to a ferroelectric state when the normal oxygen is replaced with the ^{18}O by ~36 % [$SrTi(^{16}O_{1-z}{}^{18}O_z)_3$ ($z \geq 0.36$)] [1]. The enhancement of T_C in Fig. 1 seems to be due to an increased ferroelectric fluctuation near a ferroelectric quantum critical point at (x, z) = (0, 0.36). With use of the phenomenological theory [2], the tunnelling energy relevant to the ferroelectric instability is compared among $SrTiO_{3-\delta}$ [3], $(Sr,Ca)TiO_{3-\delta}$, $SrTi_{1-x}Nb_xO_3$, and $Sr_{1-x}La_xTi(^{16}O_{1-z}{}^{18}O_z)_3$.

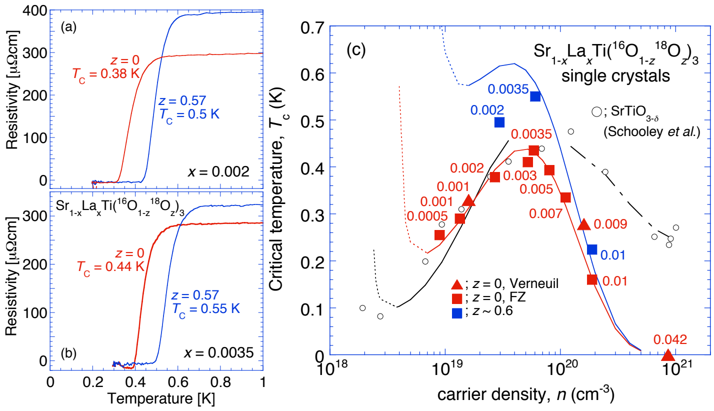

Figure 1. Superconducting transition temperatures T_c measured using a $^3He/^4He$ dilution refrigerator below 1 K for the normal (z = 0) and enriched (z ~ 0.6) crystals of $Sr_{1-x}La_xTi(^{16}O_{1-z}{}^{18}O_z)_3$ with x = 0.002 (a) and 0.0035 (b). (c) T_c vs. n for the $Sr_{1-x}La_xTi(^{16}O_{1-z}{}^{18}O_z)_3$ single crystals together with the T_c for $SrTiO_{3-\delta}$ [3] and La-substituted $SrTiO_3$ [4]. The solid (partially dashed) lines were obtained from calculations based on the model in Ref. [2].

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P65

Applications of Electron Hydrodynamics to Nonlocal and Nonlinear Optical Effects

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The conventional theory of optical responses in metals has been based on the Drude theory, which relies on the assumption that electron-electron scattering is weak enough to ignore and the transport is governed by collisions with defects or phonons. However it has become possible, in recent years, to prepare ultrapure metallic samples, such as $PdCoO_2$ [1], graphene [2], and GaAs/AlGaAs heterostructures [3], where the electron-electron scattering becomes most dominant process governing transport and thus the Drude theory is no longer valid. This regime is called ”hydrodynamic regime” and described by an emergent hydrodynamical theory [4]. In fact, several observations of hydrodynamic effects in DC transport have already been reported[1, 2, 3].

In this work, we provide a new framework of optical response in hydrodynamic regime. Based on momentum relaxing Navier-Stokes equation, we calculated the optical conductivity and regflectivity of 2D and 3D electron fluids and discuss how electromagnetic waves propagate in electron fluids. Consequently, we revealed that, in three-dimensional electron fluids, an electromagnetic wave propagates in two modes due to the nonlocality of electron fluids, which is in constrast with the Drude theory, where it propagates in only one mode. We further discuss the second harminic generation resulting from the nonlinearlity of electron fluids.

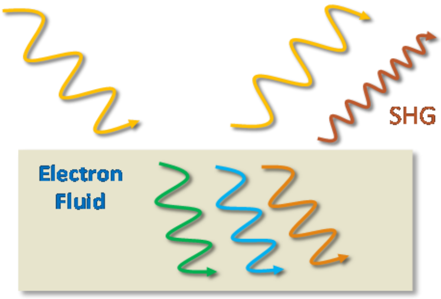

Figure 1: Schematic picture of optical responses in electron fluids. In the hydrodynamic regime, a propagating wave consists of two different transvarse waves and one longitudinal wave (plasma mode). The nonlinearlity of electron fluids causes second harmonic waves and even higher ones.

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P66

Spontaneous Hall effect in all-in all-out Weyl semimetal of pyrochlore iridate

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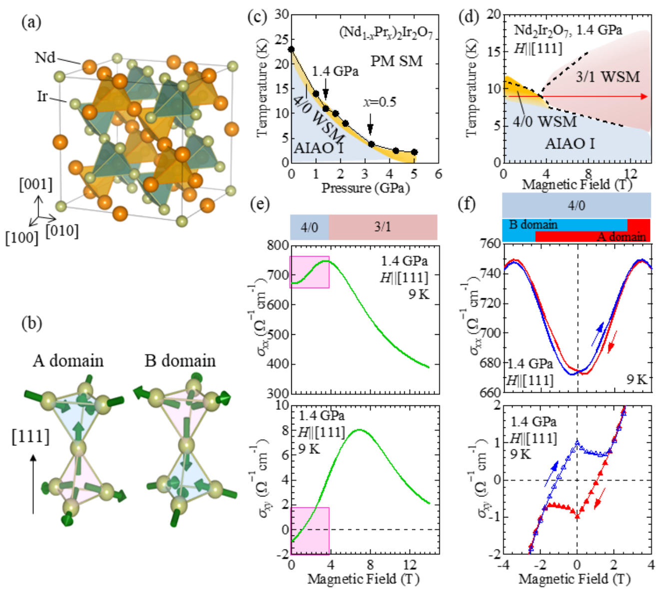
[3]*RIKEN Center for Emergent Matter Science (CEMS), Japan*

Topological quantum states of matter, characterized by geometrical features of electronic band structures, have been extensively explored and studied[1]. Among them, the topological electronic state with magnetic order or broken time-reversal symmetry remains elusive because of a scarce number of examples. Here we present experimental observations proving that the pyrochlore iridate, when electronically tuned, can be a topological Weyl semimetal as predicted theoretically[2]. By tracking transport measurements, we observe a sizable spontaneous Hall conductivity with minimal magnetization only within a few Kelvin below the all-in all-out magnetic ordering temperature as shown in the figure. Our theoretical calculation, which is quantitatively consistent with the observation, suggests that the presence of linearly-dispersing crossing points (Weyl points), acting as a source/sink of a quantized magnetic flux in *k*-space, potentially gives rise to such an enormous effect. The manifestation of the salient Hall response provides one important example of topological states, which promotes a better understanding of Weyl semimetal and indicates the new research direction for the topological-materials design and function.



Phase diagram and representative magnetic transport properties in $R_2Ir_2O_7$.

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P67

Strong-correlation induced highly mobile electrons in Dirac semimetal of perovskite $CaIrO_3$

R. Yamada[1], J. Fujioka[2,3], M. Kawamura[4], T. Okawa[1], S. Sakai[4], M. Hirayama[4], R. Arita[1,4], D. Hashizume[4], M. Hoshino[2,4] and Y. Tokura[1,4]
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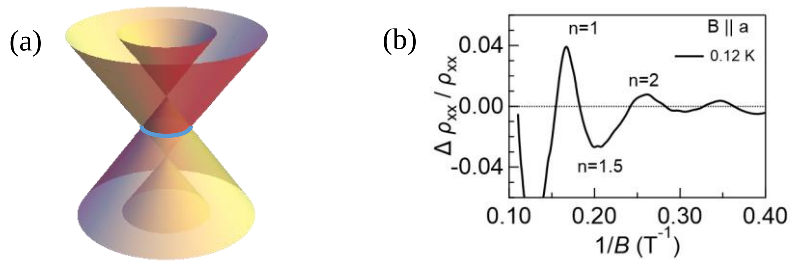
[3]*Department of Applied Physics, The University of Tsukuba, Japan*
[4]*RIKEN CEMS*

Topological semimetals have been attracting significant attention because they show unique quantum transport properties derived from highly mobile Dirac/Weyl fermions such as giant magneto-resistivity and chiral anomaly. So far, these properties have been observed mainly in weakly correlated systems such as Cd_3As_2[1] and Na_3Bi[2]. On the other hand, it is theoretically predicted that topological semimetallic state can be realized in strongly correlated materials. For example, the possible realization of a magnetic Weyl semimetal phase has been proposed in pyrochlore-type iridates[3], wherein correlated Weyl electrons manifest themselves as the giant magnetoresistivity and anomalous Hall effect. Another example is the Dirac semimetal phase in perovskite-type AIrO$_3$ (A=Ca,Sr)[4] with Dirac nodal-line protected by nonsymmorphic crystalline symmetry, wherein the conduction band and valence band cross along a closed line in momentum space as shown in Figure(a). However, the quantum transport associated with highly mobile Dirac/Weyl fermions have been rarely observed in these classes of strongly correlated topological semimetals.

In this study, we report the unique quantum transport phenomena of correlated Dirac electron in perovskite $CaIrO_3$[5]. We found that the highly mobile electrons exceeding 60,000cm^2/Vs with the quantum oscillation emerging at low temperature. Combined with ab-initio calculations, we conclude that the interplay between electron correlation and spin-orbit interaction causes the remarkable proximity of Dirac node to the Fermi energy, yielding the highly mobile electrons.



(a) Band structure around Dirac nodal-line. (b) Quantum oscillation observed in longitudinal magnetoresitivity.

[1] T. Liang *et al*., Nat. Matter. **14**, 280 (2015) [2] J. Xiong *et al*., Science **350**, 6259 (2015)
[3] K. Ueda *et al*., PRL **115**, 056402 (2015) [4] M. Zeb and H. Kee, PRB **86**, 085149 (2012)
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P68

Fate of loss-induced superconductivity studied by non-Hermitian mean field theory

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[1]*Department of Physics, Kyoto University*

When we consider the effects of dissipation such as loss of particles or inelastic scattering, Hamiltonian of the system is no longer Hermitian but could be non-Hermitian because dissipation may cause non-unitary dynamics of the system, leading to the decay of eigenstates. In recent years, non-Hermitian quantum systems have been extensively studied both experimentally and theoretically [1–4]. However, most of the previous studies dealt with systems without interaction and there have been few studies focusing on quantum many-body phenomena. In this study, we investigate how the BCS superconductivity, a prototypical example of quantum many-body phenomena, changes its character when the effects of dissipation are taken into account. In the presence of two-particle loss, the attractive potential forming Cooper pairs becomes complex. Such a situation can be realized experimentally, for example, as the Orbital Feshbach Resonance (OFR) where the interaction between the ground ${}^1S_0$ state and excited ${}^3P_0$ state in ultracold alkaline-earth atoms becomes complex because of dissipation. Furthermore, as the experiments to realize superfluids using OFR by controlling the interaction between different orbitals have been actively conducted these days, it is particularly important to investigate the stability of superfluids in the system under dissipation. We calculate the action from the partition function using Hubbard-Stratonovich transformation and neglecting quantum and space fluctuations. Then we obtain the gap equation for the dissipative superconducting system by taking the saddle point of the action. We elucidate the fate of Hermitian superconductivity by taking the real part of the gap focusing on short-time non-Hermitian dynamics: at a critical strength of dissipation (imaginary part of interaction), the superconducting gap closes, leading to a breakdown of BCS superconductivity. We finally show how the BCS mean-field theory in open quantum systems is changed from its Hermitian one and the corresponding superconducting gap under dissipation is expressed by the expectation value of fermionic operators.

Acknowledgement: This work is done in collaboration with Kazuaki Takasan (Kyoto Univ.), Kyosuke Adachi (Kyoto Univ.), Masaya Nakagawa (RIKEN), Masahito Ueda (Univ. of Tokyo & RIKEN).

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[2] Takafumi Tomita et al. *Science Advances* **3** (2017) e1701513.

[3] Yuto Ashida, Shunsuke Furukawa, Masahito Ueda, *Nature Communications* **8** (2017) 15791.

[4] Masaya Nakagawa, Norio Kawakami, Masahito Ueda, *Physical Review Letters* **121** (2018) 203001.

P69

Quantum critical phenomena in heat transport in the subohmic spin-boson system

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Institute for Solid State Physics, The University of Tokyo, Japan

Quantum critical phenomena are ubiquitous in condensed matter physics. Recent technological progress has enabled to realize nanostructures and observe quantum critical phenomena via electric transport in mesoscopic systems[1]. This success encourages further study of quantum critical phenomena in different types of transport in well-controlled mesoscopic systems.

Heat transport via nanostructures is another important topic in mesoscopic physics. In particular, heat transport in the spin-boson system is one of the most common and important models for describing a local discrete-level system coupled to bosonic thermal reservoirs (see Figure 1) and has been studied in a number of theoretical studies[2]. Depending on the spectral density of the thermal reservoirs, $I(\omega) \propto \omega^s$, the processes of heat transport change. Intriguingly, the subohmic spin-boson model ($0 < s < 1$) shows a quantum phase transition at zero temperature when a coupling strength between the two-state system and thermal reservoirs becomes critical value.

In the present study[3], we consider quantum critical phenomena in heat transport in the subohmic spin-boson system. We numerically investigate the temperature dependence of the thermal conductance at the critical point using the continuous-time Monte Carlo simulation[4]. We show that the thermal conductance exhibits distinctive power-law behavior determined by the nature of the quantum phase transition near the quantum critical point. In addition, we present a scheme for the realization of the subohmic spin-boson model using a superconducting circuit.

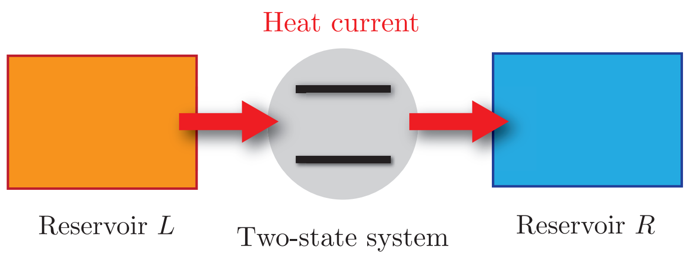

Figure 1: Schematic of the spin-boson model composed of a two-state system coupled to two bosonic thermal reservoirs.

[1] Z. Iftikhar *et al.*, Science **360**, 1315 (2018).
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P70

Local magnetic excitations in Weyl semi-metals explored by NMR and NQR spectroscopy.

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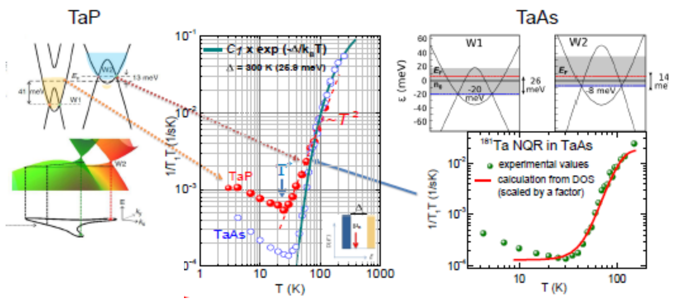
The topological nature in condensed matters is one of the most fascinating areas of advanced research in solid state physics. Among them, as is represented by Graphene, some cases of semi-metals have a nontrivial linear dispersion of the band structure touching at the Fermi energy, forming a Dirac point. Upon breaking the centro-symmetry of crystal and/or the time reversal symmetry, each Dirac point splits into two points called Weyl points with spin degeneracy lifted and have a topological nature [1]. The Weyl fermions at these Weyl points appear as a pair with opposite spin chirality due to strong spin-orbit coupling. For the application side, Weyl fermions are expected to be a good candidate for the ultra-high speed and low energy electronic devices. Beyond that, new physics like anomalous Hall effect (Hall voltage without field) and chiral anomaly (generate current along field) has been anticipated.

Here, we present microscopic "bulk" properties in several Weyl semimetals, focusing on those low-lying magnetic excitations. Utilizing NMR and NQR techniques, we made detailed measurements on the T-dependences of line profiles to extract $K(T)$, $\nu_Q(T)$, and nuclear relaxation rate ($1/T_1T$), both of which gave us a characteristic feature associated with the Weyl physics. As a typical example, the results for $1/T_1T$ (T) in TaP and TaAs are presented in Figure 1. For both cases, there exists a characteristic temperature, $T^* \approx 30$ K, where the relaxation process has a crossover from low temperature Korringa process for a parabolic band with a weak temperature dependence to a high temperature activation type T-dependence. For TaP, in particular, we observed the T^2 behavior above T^* which is associated with the excitations in the nodal structure of Weyl points [2] with a characteristic T-dependence of hyperfine coupling associated with the Weyl fermions [3]. We will also discuss extended our results on the Weyl-II semi-metals, WP_2 and $MoTe_2$.



<u>Fig. 1</u> *Typical T-dependence of $1/T_1T$ in Type-I Weyl semimetals, TaP and TaAs.*

[1] F. Arnold, et.al. Nature Communications 7, 11615 (2016)

[2] H. Yasuoka et.al., PRL 118 (2017) 236403

[3] Okvatovity et.al., PRB 92, 245141 (2016), Hiropsawa et.al., JPSJ 86 063705 (2017)

P71

Creation of skyrmions by surface acoustic waves

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Skyrmion, nanometric topological spin texture, gives rise to various unique physical phenomena. Especially, because of ultralow current driven motion of skyrmion, skyrmion is considered as a promising candidate for an information bit in new magnetic storage devices [1,2]. Recently, the formation of Neel-type skyrmion (Fig. 1) at room temperature is reported in multilayer thin films in which magnetic metal is sandwiched by two heavy metals [2,3]. This has accelerated the research on the development of skyrmion-based storage devices. In particular, the creation of skyrmion by external stimuli is one of the most important element in order to realize the skyrmion-based storage devices. So far the creation of skyrmions has been demonstrated by employing local spin-orbit torque arising from deliberate geometrical shapes of multilayer films [3,4]. However, these methods are not exactly suitable for integrated nanoscale devices because the geometric structures designed for the skyrmion creation occupies a large area.

In this presentation, we demonstrate a novel mechanism for the creation of skyrmion, that is, surface acoustic waves induced skyrmion creation. A stack of Pt/Co/Ir was deposited on $LiNbO_3$ substrate and surface acoustic waves were excited by using interdigital transducers (IDTs). We used a Kerr microscope in polar geometry to observe magnetic structures. When the surface acoustic wave is excited in the ferromagnetic state, skyrmions appear, which indicates surface acoustic waves creates skyrmions. To clarify the mechanism for the skyrmion creation induced by surface acoustic waves, we performed micromagnetic simulation, finding that modulated magnetic anisotropy arising from the surface acoustic waves locally reverses spins and the reversed spins subsequently grow into the core of Neel-type skyrmion. Our results offer a novel guiding principle for a means to create skyrmions in ultrathin films.

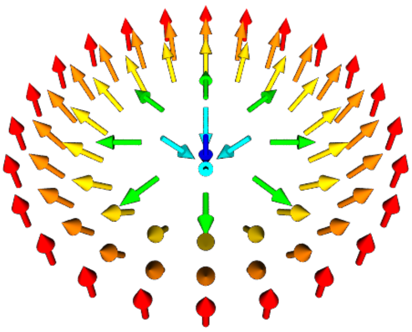

Figure 1 Neel-type skyrmion

[1] N. Nagaosa and Y. Tokura, Nat. Nanotech. **8**, 899 (2013).
[2] A. Fert, V. Cros and João Sampaio, Nat. Nanotech. **8**, 152 (2013).
[3] W. Jiang *et al*., Science **349**, 283 (2015).
[4] F. Büttner *et al*., Nat. Nanotech. **12**, 1040 (2017).

P72

Symmetry-protection of exceptional points for correlated systems in equilibrium

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In this decade, it has been revealed that symmetry enriches topological phases of condensed matters. For instance, time-reversal symmetry protects the topology of the Z_2 insulators in two- and three-dimensional systems. Z_2xZ_2 symmetry in the spin-space protects the Haldane phase of spin-one systems. This diversification is observed even for topological gapless modes emerging in topological semi-metals.

Along with this great success, the platform of topological phases has extended to non-Hermitian systems where a variety of exotic topological states are reported. In particular, in non-Hermitian systems, Hamiltonian may violate diagonalizability, resulting in the emergence of exceptional points[1]. The exceptional points do not require any symmetry-protection, and the emergence of them are theoretically reported even for correlated systems in equilibrium [2,3].

The above two significant progresses naturally lead us to the following question: "What are new phenomena arising from interplay of symmetry and exceptional points?" We address this issue in this presentation. Our analysis uncovers the novel topological degeneracies: symmetry- protected exceptional rings in two dimensions. In the presentation, we show how symmetry protects these novel topological degeneracies by taking chiral symmetry as an example.

[1] H. Shen, B. Zhen, and L. Fu, Phys. Rev. Lett. **120**, 146402 (2018).
[2] V. Kozii and L. Fu arXiv. 1708.05841.
[3] T. Yoshida, R. Peters, and N. Kawakami , Phys. Rev. B **98**, 035141 (2018).
[4] T. Yoshida, R. Peters, N. Kawakami, and Y. Hatsugai, arXiv: 1810.06297.

P73

Investigation of Ir magnetism in $LaMnO_3/SrIrO_3$ superlattices by hard x-ray magnetic circular dichroism

Yujun Zhang[1], Liang Wu[2], Motohiro Suzuki[3], Yasuyuki Hirata[1], Kohei Yamagami[1], Keisuke Ikeda[1], Kohei Yamamoto[1], Xin Liu[4], Jinxing Zhang[4], X. Renshaw Wang[5], Yuanhua Lin[2], Cewen Nan[2], Hiroki Wadati[1]

[1]*Institute for Solid State Physics, The University of Tokyo, Japan*

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[3]*JASRI, Japan*

[4]*Department of Physics, Beijing Normal University, China*

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Entanglement and coupling of charge, spin, lattice and orbital degrees of freedom in transition metal oxide (TMO) systems have attracted much attention in recent years [1]. Fabrication and investigation of materials systems with both strong electron correlation and strong spin-orbital coupling (SOC) are of both scientific and technical interest. Artificially synthesized 3*d*/5*d* TMO heterostructure or superlattice can be promising candidates to involve significant correlation and SOC simultaneously [2,3]. In this work we investigated hard X-ray magnetic circular dichroism (XMCD) of $[(LaMnO_3)_n/(SrIrO_3)_n]_m/SrTiO_3$ superlattices (n=1,2,8; m=24,12,3; named as SL11, SL22 and SL88) at Ir $L_{2,3}$ edge. All the superlattices show XMCD signal (as shown in Figure 1) below the ferromagnetic ordering temperature, which is confirmed by temperature dependence of the XMCD signal. Sum rule analysis is applied to analyze the spin and orbital moment of Ir. These results indicate that the Ir magnetic moment can be strongly modified by interfacial coupling between 3*d* and 5*d* TMO layers.

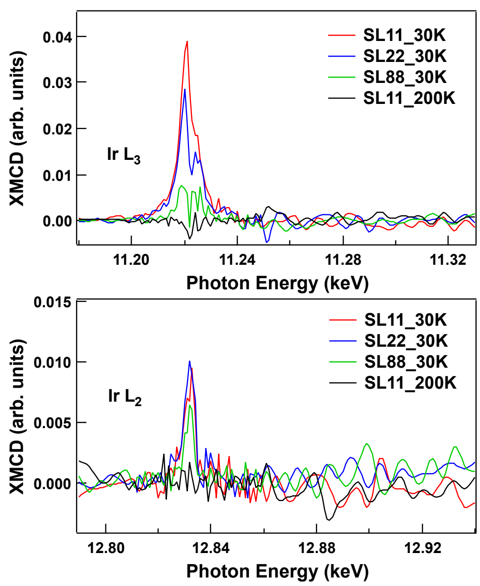

Figure 1. Ir *L* edge XMCD spectra of the superlattices

[1] Dagotto E. (2005). *Science* 309(5732): 257-262.

[2] Matsuno J., et al. (2015). *Phys. Rev. Lett.* 114(24): 247209.

[3] Yi D., et al. (2016). *Proc. Natl. Acad. Sci. USA* 113(23): 6397-6402.

P74

Comparison of Spin Hall Angles for Epitaxial and Polycrystalline Platinum Thin Films

Z. Zhu[1], T. Higo[1,2], J. Kim[3], K. Matsumoto[1], H. Isshiki[1], D. Qu[1], K. Kondou[3], S. Nakatsuji[1,2] and Y. Otani[1,2,3]

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[2]*JST CREST, Japan*

[3]*RIKEN-CEMS, Japan*

Platinum (Pt) is widely used in pure spin current spintronics and one of the most studied spin Hall material. The first attempt to make a quantitative measurement of the spin Hall angle (θ_{SH}) for Pt was reported by Kimura et al. [1]. However, different values of the θ_{SH} have also been reported by other groups. The origin of the dispersed θ_{SH} values has not been understood until recent experimental report [2], where different polycrystalline Pt resistivity is one of the main reasons for the spread of θ_{SH} values. The contribution of extrinsic spin Hall effect mechanism is enhanced in Pt with larger impurities, leading to a higher θ_{SH} value in lower conductivity Pt. On the other hand, for single crystalline platinum with higher conductance than polycrystalline platinum, it is ambiguous how θ_{SH} values change. To understand the large difference in θ_{SH} values, the effect of crystallinity on θ_{SH} values is indispensable. In this work, we have studied both epitaxial and polycrystalline Pt films to clarify the effect of crystallinity on the spin Hall properties.

In Our study, Pt thin films on both sapphire and Si/SiO$_x$ substrates were fabricated using the magnetron sputtering at a substrate temperature of 550°C. The crystallographic structure of Pt thin films was measured by x-ray diffraction (XRD). Figure 1 shows XRD patterns of *2θ-θ* scan and *φ*-scan for Pt thin film on the sapphire substrate. The six-fold symmetry for Pt (002) indicates that the epitaxial Pt is successfully grown on Sapphire (001).

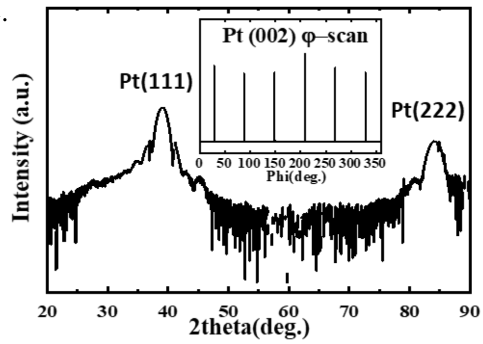


Figure 1: XRD patterns of *2θ-θ* scan and *φ*-scan (inset) for Pt thin film on the sapphire substrate.

We then studied the spin Hall magnetoresistance (SMR) in the Pt/Co/AlO$_x$ multilayers to estimate the θ_{SH} for the epitaxial Pt.

[1] Kimura, T., Otani, Y., Sato, T., Takahashi, S., & Maekawa, S., *Physical review letters*, *98*, 156601 (2007).

[2] Sagasta, E., Omori, Y., Isasa, M., Gradhand, M., Hueso, L. E., Niimi, Y., Otani, Y., & Casanova, F., *Physical Review B*, *94*, 060412 (2016).

Information for participants

TPFC2019, day 1 (Feb. 18)

1. First, resister your attendance at the registration desk (9:15-10:00).

2. At the registration desk, please also **pay the banquet fee** (4,000 JPY), if you are attending the conference dinner.

TPFC2019, day 2 (Feb. 19)

1. Please register for the day at the registration desk. TPFC symposium is requested to confirm their attendance every day.

2. The poster preview session will be held concurrently with the extended lunch break. A complimentary light meal will be provided on the site. **Please also note that nearby coffee shop Tully's and the restaurants in the Lalaport shopping mall are unfortunately closed on this day**.

3. Before the lunch/poster session, group photos will be taken. Please follow the instruction from the TPFC organizers.

4. A conference dinner will follow the symposium on this day.

Conference Dinner

The conference dinner will be held on Tuesday evening, February 19, at Comesta (Italian restaurant) on the first floor of Mitsui Garden Hotel Kashiwano-ha.

http://comestadome.jp/kashiwanoha/ [in Japanese]

Fee: **If you join the conference dinner, please pay the banquet fee of 4,000 JPY at the registration desk on the first day**.

Cancellation: If you have expressed your intention to attend the dinner but become unfortunately unable to attend it, please let us know immediately but no later than Feb 18. **Cancellation notice after this will result in a cancellation charge**.

Participation w/o prior reservation: Conversely, if you become able to join the banquet even though you previously told us you would not be able to, please let us know as soon as possible. Some seats are still available.

Poster preview session

Prior to the poster session, on 19th in 12:20-14:20, a “poster preview session” is scheduled for each poster presenter to provide a brief introduction on her/his poster **using one slide in one minute**.

Poster awards

All poster presenters are the candidates for poster awards. The poster award winners will be chosen by the invited speakers and senior participants during the poster session. **The winners will be announced and celebrated during the conference closing ceremony on February 20 at 5 PM.**

TPFC2019, day 3 (Feb. 20)

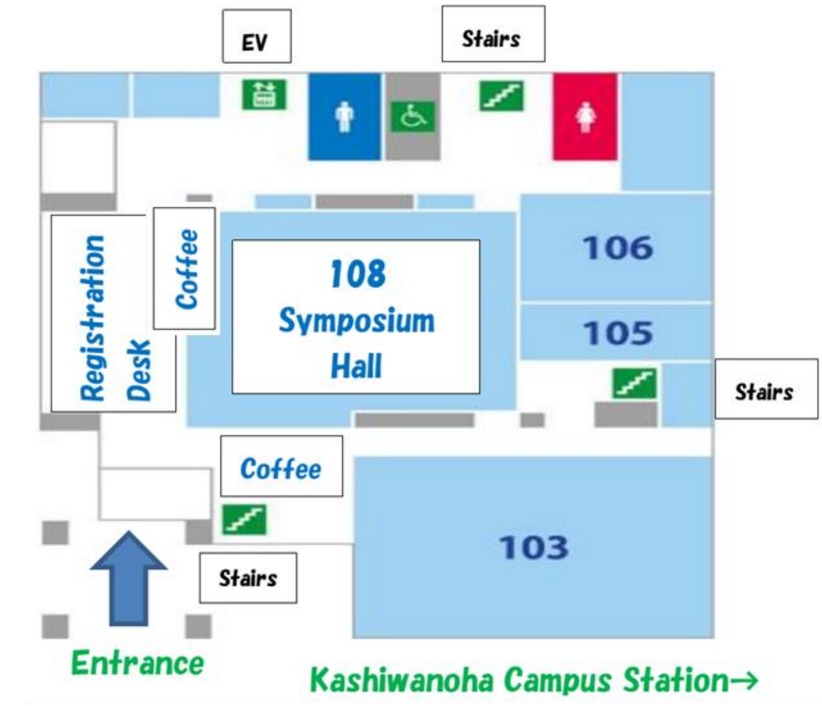
1. Please register for the day at the registration desk.

2. **Please return your name holder** when you leave.

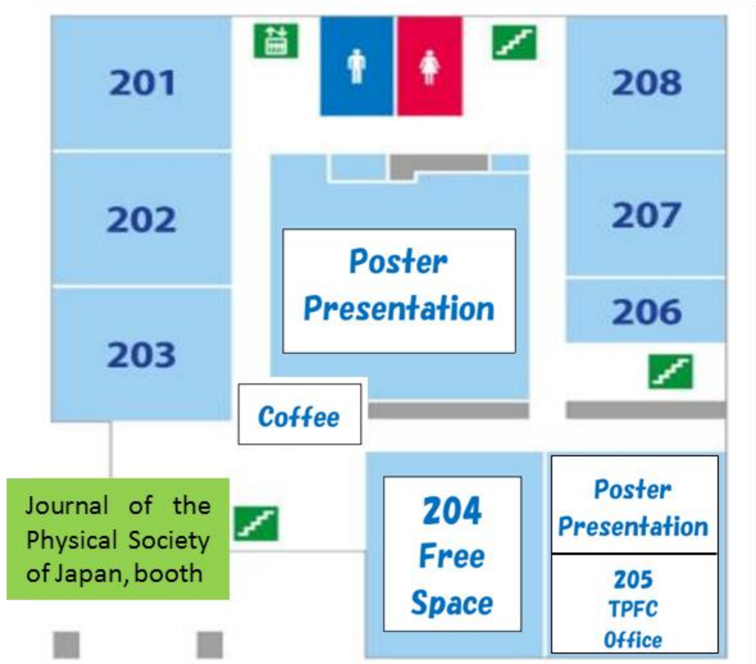
Venue Floor Map

(Kashiwa Campus Station Satellite)

1st floor



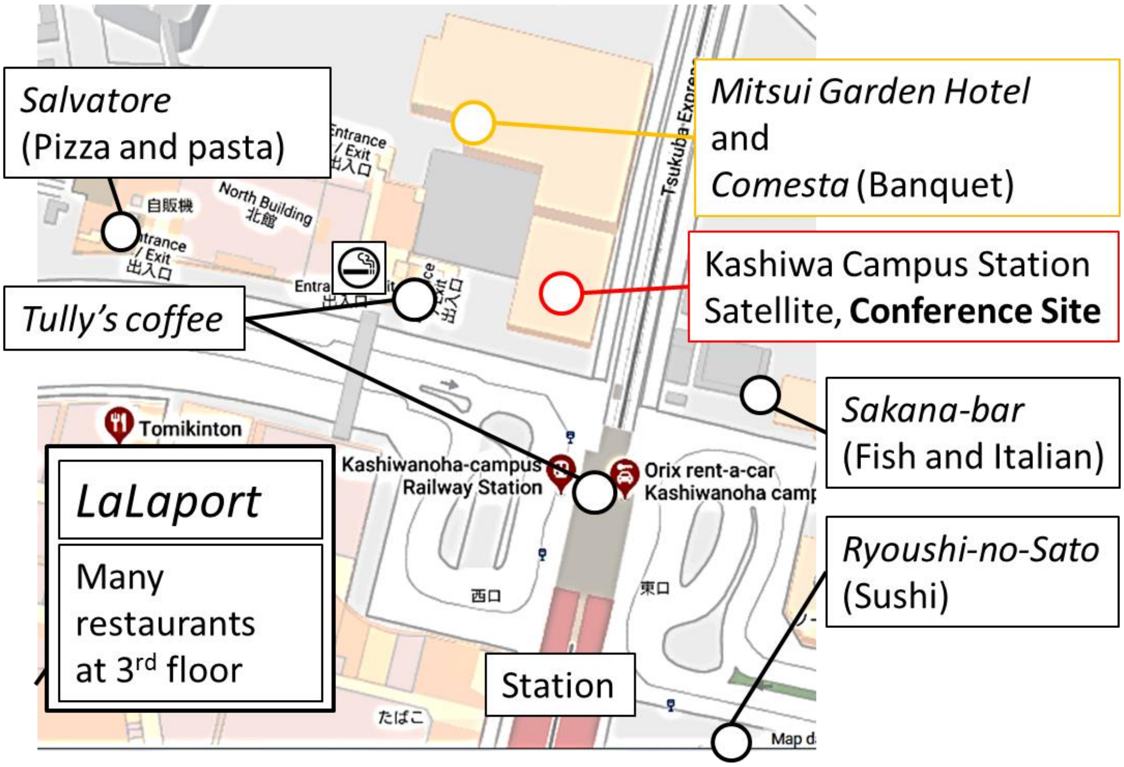
2nd floor



Where to Eat

A wide variety of restaurants and a food court are available on the third floor of the Lalaport shopping mall http://kashiwa.lalaport.jp/en/shopguide/gourmet.html. The restaurants there open from 10:00 or 11:00 to 21:00/ 22:00 (Hours vary from restaurant to restaurant. For details, please check the website.) **Please note that Lalaport will be closed on Tuesday, Feb. 19 for its regular statutory inspection. We will serve a light meal as lunch for the participants in the Symposium on Feb. 19.**

For breakfast, the restaurant in the Mitsui Garden Hotel serves breakfast. However, we generally do not arrange breakfasts at the Hotel even if we booked a room for you. You can request breakfasts at the Hotel by yourself but there will be an additional fee. For less expensive breakfast menus, a MacDonald's and a Tully's Coffee are located near the hotel/station. You can also buy boxed meals, sandwiches, rice balls, brewed coffee, etc. at the Lawson and Family Mart convenient stores. The former is located in front of the Mitsui Garden Hotel and the latter is next to the train station.



General information

Directions

To TPFC Symposium Venue (Kashiwanoha Campus Station Satellite of UTokyo)

http://tpfc.issp.u-tokyo.ac.jp/venue.htm

*Note: The Symposium Venue is just at the front of the Kashiwanoha-Campus railway station and next to Mitsui Garden Hotel.

How to Get Around (Public Transportation)

To get around the greater Tokyo area (including the Kashiwanoha Campus area), the best way is to use public transportation. To figure out the best route to your destination, this online planner may be helpful: https://world.jorudan.co.jp/mln/

To make things easier, it is highly recommended to buy a prepaid train card, “Pasmo” (http://www.pasmo.co.jp/en/) or “Suica” (http://www.jreast.co.jp/e/pass/suica.html). With this rechargeable e-card, you don’t have to go through the hassle of buying a ticket every time you change trains; All you need to do is to scan the card at the gate (on entry and on exit). The train fare is automatically deducted from the prepaid card’s balance at the station gates.

You can buy a Pasmo card from ticket machines at the Narita Airport/ Airport Terminal 2 Station (http://www.keisei.co.jp/keisei/tetudou/skyliner/us/faq/index.php). To get a new card, you need to pay a deposit of 500 JPY, which will be refunded together with the remaining balance when you return the card. The e-card can be used for trains, subways, buses, vending machines, some shops and convenient stores, and our campus co-op shops and cafeterias.

Suica cards can be bought from ticket vending machines at JR stations. A refundable deposit of 500 yen is also required. Although the refund of the deposit does not involve any fees, the refund of the remaining balance on your Suica card requires a service charge of 220 yen (which is deducted from the remaining balance). To avoid payment of this charge, you may want to use up the full balance on your card before returning a card to the ticket counter. If the balance is zero, no service fee will be charged but you will still be able to receive the 500-yen deposit.

Cash, Credit Cards & ATMs

Although credit cards are increasingly accepted, cash is still the major payment method in Japan. Indeed, smaller retailers often accept cash only. We therefore would like to advise you to prepare sufficient cash before arriving at ISSP, especially if you are staying the Kashiwa Guest House, where your bill must be paid in cash. If needed, you can withdraw cash from an ATM of Japan Post Bank https://www.jp-bank.japanpost.jp/en/ias/en_ias_index.html or Seven Bank http://www.sevenbank.co.jp/intlcard/index2.html. Before leaving for Japan, please make sure your credit or debit card is available for use in Japan and check service charges for international withdrawals.

Around the symposium/workshop venues, you can find ATMs accepting non-Japanese cards in the locations specified below. In addition to these locations, automated teller machines of Japan Post Bank and Seven Bank accept foreign cards. Unfortunately, you cannot withdraw cash with your cards issued outside Japan at other domestic banks' ATMs, including those on the Kashiwa campus.

Japan Post Bank	On the first floor of Lalaport Kashiwanoha	10:00-21:00 daily
	In the Japan Post's Kashiwanoha Campus Branch, near the Kashiwanoha Campus Station.	8:00-21:00 daily
Seven Bank	York Mart (About 5 min. walk from the Kashiwa campus)	9:00-22:00 daily
	Seven Eleven stores	24 hours

Sightseeing

http://tpfc.issp.u-tokyo.ac.jp/sightseeing.htm

If you would like to know where to visit and how to get around in the greater Tokyo metropolitan areas, you can find a lot of useful resources on the Internet. Here are a couple of useful sites:

http://www.gotokyo.org/en/index.html

https://www.japan-guide.com/e/e2019.html

https://www.lonelyplanet.com/japan/tokyo#interests

(Note: We have no affiliation with any of these services or websites.)