物性研究所セミナー

標題：From Chiral Electronics to Mottness in Momentum-Space
日時：2024 年 11 月 7 日(木) 午後 3 時～午後 4 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）
講師：Niels B.M. Schröter **氏**
所属：Max Planck Institute of Microstructure Physics
要旨：

The term chirality is derived from the Greek word for 'hand' χειρ (kheir) and describes object s that are distinct from their mirror image. It is long known that chirality plays a crucial role in nature, providing powerful functionality to chiral molecules in living organisms. By extending this concept from the molecular to the solid state, my group aims to uncover new chirality-enabled phenomena that could form the basis for new technologies.

The focus of my talk will be on chiral topological semimetals, an emerging class of quantum materials at the intersection of structural and electronic chirality. These materials can host new fermionic quasiparticles without analogue in high-energy physics (1–4), which carry large and controllable topological charges (5). We have recently demonstrated that these quasiparticles realize an isotropic Weyl-type parallel spin-momentum locking that can be considered the natural counterpart of Rashba spin-orbit coupling (6). Moreover, I will present fingerprints of controllable orbital angular momentum monopoles in these materials (7), which could be exploited in memory devices for field-free switching of magnets with perpendicular magnetic anisotropy.

Time permitting, I will also present our investigation of the origin of the magnetic field-induced (8) and field-free (9) Josephson diode effect. For the latter, we identify a momentum-resolved signature of Mottness that allows us to distinguish band-insulators from unconventional Mott-insulators with an even number of electrons.

1. N. B. M. Schröter et al., Nat. Phys. 15, 759–765 (2019).
2. Z. Rao et al., Nature. 567, 496–499 (2019).
3. D. Takane et al., Phys. Rev. Lett. 122, 076402 (2019).
4. D. S. Sanchez et al., Nature. 567, 500–505 (2019).
5. N. B. M. Schröter et al., Science. 369, 179–183 (2020).
6. J. A. Krieger et al., Nat Commun. 15, 3720 (2024).
7. Y. Yen et al., Nat. Phys. (2024) 10.1038/s41567-024-02655-1
8. B. Pal et al., Nat. Phys. 18, 1228–1233 (2022).
9. H. Wu et al., Nature. 604, 653–656 (2022).

標題：Spin splitting and cross correlation in altermagnets
日時：2024 年 11 月 8 日(金) 午後 4 時～午後 5 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）
講師：Hitoshi Seo
所属：RIKEN CPR & RIKEN CEMS
要旨：

Altermagnet is a class of antiferromagnets showing a staggered spin ordering with wave vector q = 0, while its net magnetization is cancelled out in the limit of zero relativistic spin-orbit coupling. The simplest case is when the up and

down spins are ordered on two sublattice sites within the unit cell which are not connected by either translation or inversion. Consequently, the system breaks the macroscopic time-reversal symmetry and exhibits non-relativistic spin splitting in the energy band and characteristic cross-correlation phenomena.

In this talk, I will introduce our theoretical studies based on effective models for correlated electrons in k-type organic compounds [1] and perovskite-type transition metal compounds [2]. In these systems, the dimeric molecular arrangements and the GdFeO3-type lattice distortions, respectively, play the role of the crystallographic setting for altermagnetism. We show that antiferromagnetic orderings give rise to the non-relativistic spin splitting, owing to anisotropic sublattice dependent (and thus spin dependent) electron hoppings, and its consequent spin current generation, and the anomalous Hall effect in the presence of the spin-orbit coupling. Recent developments will also be discussed.

[1] M. Naka et al., Nat. Comm. 10, 4305 (2019); M. Naka et al., Phys. Rev. B 102, 075112 (2020); H. Seo and M. Naka, J. Phys. Soc. Jpn. 90 064713 (2021); S. Sumita, M. Naka, and H. Seo, Phys. Rev. Res. 5, 043171 (2023).
[2] M. Naka, Y. Motome, and H. Seo, Phys. Rev. B 103, 125114 (2021); M. Naka, Y. Motome, and H. Seo, Phys. Rev. B 106, 195149 (2022).

標題：タンパク質構造予測 AI:AlphaFold のリバースエンジニアリングと分子シミュレーション
日時：2024 年 11 月 11 日(月) 午後 4 時～午後 5 時
場所：物性研究所 6 階 A612 及び Online
講師：岡崎 圭一
所属：分子科学研究所
要旨：

2021 年に DeepMind 社から公開された AlphaFold2（AF2）は高精度なタンパク質構造予測を達成し、広い分野に革命を起こした。そして、先日 2024 年ノーベル化学賞を受賞したところである。ただし、深層学習ベースの複雑な仕組みのため、なぜこのような高精度予測が可能なのか必ずしも明らかではない。また、静的な単一構造予測を超えた動的な構造変化の予測が可能なのか議論になっている。本講演では、リバースエンジニアリング的なアプローチにより、AF2 の仕組みをタンパク質フォールディングにおけるエネルギー地形の観点から解説し、構造変化予測について議論する。さらに、トランスポータータンパク質を例にとって、AF2 と分子シミュレーションを統合することで機能的構造変化を解明した研究についてお話しした。

標題：金属強磁性体における光誘起非相反相転移
日時：2024 年 11 月 21 日(木) 午前 10 時～午前 11 時 30 分
場所：物性研究所本館 6 階 第 6 セミナー室（A616）
講師：花井 亮
所属：京都大学 基礎物理学研究所
要旨：

外部からのエネルギー注入がある非平衡開放系では、一般に作用反作用の法則が破れた非相反相互作用が生じうる。実際、脳科学、生態学、生物系からロボティックスに至る幅広い非平衡系で普遍的に非相反相互作用は現れることが知られている。近年、この非相反相互作用により巨視的物理量が「追いかけっこ」をする時間結晶相へと相転移することが見出され注目を集めている[1]。本発表では、非相反相互作用/相転移を固体電子系で光誘起する方法を提案する[2]。具体的には、金属強磁性体の局在スピン間相互作用の素過程に光によりエネルギー注入することにより、非相反 RKKY 相互作用

を及び非相反相転移を引き起こす方法を提案した。

[1] M. Fruchart*, R. Hanai*, et al., Nature 592, 363 (2021).
[2] R. Hanai, D. Ootsuki, and R. Tazai, arXiv:2406.05957 (2024).

標題：Quantum geometric properties and anomalous Hall effects in twisted TMDs
日時：2024 年 11 月 26 日(火) 午後 2 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）
講師：Prof. Wang Yao
所属：The University of Hong Kong
要旨：

Abstract: This talk will discuss quantum geometric properties of electrons in homobilayer semiconductors arising from the layer pseudospin when twisting introduces its texture in real and momentum spaces. In small angle twisted transition metal dichalcogenides (TMDs), real-space Berry curvature from the moiré-patterned layer pseudospin texture realizes an effective magnetic field that underlies the emergence of quantum anomalous Hall (QAH) effects recently observed in t-MoTe2. We show an intrinsic dipole Hall effect in both the ferromagnetic and antiferromagnet QAH states at integer fillings of the moiré, which leads to a novel magnetoelectricity. This allows contact-free detection of the topological transitions to QAH states, signified by a sudden sign switch of the magnetoelectric susceptibility. I will also discuss a bipartite limit of the fluxed three-orbital tight-binding model we initially proposed for twisted TMDs, featuring a singular flatband with band touching, where DMRG and ED calculations surprisingly reveal fractional QAH phases at its fractional fillings. Gapping the touching point turns singular flat band into a Chern band, but counter-intuitively, the fractional QAH phase gets quenched, which may be attributed to the variation in Berry curvature distribution upon the gap opening. If time allows, I will also briefly cover linear and nonlinear responses of quantum geometric origins from momentum space layer texture.

標題：テラヘルツ電場駆動 STM と STM 発光分光法の融合による新規分光手法の開拓
日時：2024 年 11 月 27 日(水) 午後 1 時 30 分～午後 3 分
場所：D 棟 D120
講師：木村 謙介
所属：理化学研究所
要旨：

単一分子を可視化できる走査トンネル顕微鏡(STM)に発光検出技術を組み合わせることで、STM のトンネル電流を励起源とした発光測定が可能であり、原子スケールの高い空間分解能で光学特性を調べることが可能である[1-2]。一方で、励起源として用いられるトンネル電流は電気回路により定常的に流れていることから、STM 発光測定の時間分解能は限られてきた。そこで、我々はシングルサイクルテラヘルツ(THz)パルスを用いて STM のトンネル電流を超高速に駆動する技術に注目し[3-4]、THz-STM と STM 発光の融合による新規分光手法の開発に取り組んできた[5]。本講演では、THz 電場駆動トンネル現象により単一分子を励起して、分子からの蛍光を検出することに近年成功したので紹介した。

[1] H. Imada, et al., Nature 538, 364 (2016).
[2] K. Kimura, et al., Nature 570, 210 (2019).
[3] T. L. Cocker, et al., Nat. Photon. 7, 620 (2013).
[4] K. Yoshioka, et al., Nat. Photon. 10, 762 (2016).
[5] K. Kimura, et al., ACS photon. 8, 982 (2021).

標題：Quantum criticality and emergent Lorentz symmetry in non-Hermitian Dirac materials
日時：2024 年 11 月 27 日(水) 午後 1 時～午後 2 時
場所：物性研究所本館 6 階 第 6 セミナー室（A616）および Online（**ハイブリッド開催**）
講師：Prof. Bitan Roy
所属：Lehigh University, PA, USA
要旨：

From the Standard model for elementary particles to various quantum crystals, such as graphene, the dynamics of underlying fermionic degrees of freedom is governed by the Dirac Hamiltonian that manifestly preserves the Lorentz symmetry. In this talk, first I will propose a general construction of the Lorentz invariant Dirac operator in non-Hermitian (NH) systems, featuring two velocity parameters vH and vNH, associated with the Hermitian and anti-Hermitian components of such operators, respectively. I will show that in such noninteracting systems, all the observables, such as the energy spectrum, density of states, and frequency dependent optical conductivity and shear viscosity are governed by an effective Fermi velocity vF = (vH2– vNH2)1/2. Next, I will consider interactions between NH Dirac quasiparticles and bosonic degrees of freedom, such as (a) the scalar order-parameter fluctuations mediated by short-range Hubbard-like repulsions, yielding Yukawa interactions and (b) relativistic helical photons, giving rise to NH quantum electrodynamics. In both scenarios, although the system primarily loses the Lorentz symmetry at the lattice or ultraviolet scale, it gains a NH Lorentz symmetry through various quantum corrections in the deep infrared regime in terms of a unique terminal velocity for all the participating degrees of freedom, generically tagged as the speed of light. If time permits, I will show such a generic outcome for spin-3/2 NH birefringent Dirac fermions toward the end of the talk.

References:
V. Juricic and B. Roy, Communications Physics 7, 169 (2024)
Sk A. Murshed and B. Roy, Journal of High Energy Physics 2024, 143 (2024)
Sk A. Murshed and B. Roy, arXiv:2407.18250

標題：有機磁性体の磁気格子設計と量子磁気状態
日時：2024 年 11 月 28 日(木) 午前 11 時～午後 0 時
場所：Online
講師：細越裕子教授
所属：大阪公立大学
要旨：

有機化合物のπ電子スピンは、電子スピンの量子力学的性質が顕著に表れる特徴を持つ。スピン密度が、π共役系を介して分子全体に拡がる特徴を利用して、結晶中のスピン空間構造を制御できる。本セミナーでは、こうした背景とともに、最近の研究成果として、次近接相互作用を持つ反強磁性スピンラダーの温度-磁場相図とスピン液体相、飽和磁場近傍に現れる非自明磁気相、フラストレート二次元磁性体の磁場中磁気状態などを紹介した。

また、ライフステージを振り返り、男女共同参画推進事業との関わりなどについても触れた。

標題：Altermagnetism from electronic correlations
日時：2024 年 12 月 5 日(木) 午後 3 時 30 分～午後 4 時 30 分
場所：Online
講師：Sonia Haddad 氏
所属：Faculte des Sciences de Tunis, Universite Tunis El Manar
要旨：

Altermagnetism has recently been proposed as a third class of magnetic materials.

Altermagnetic materials are characterized by a vanishing net magnetic moment and a spin polarized electronic band structure.

Their symmetry in principle allows for the existence of an anomalous Hall effect. Altermagnetic materials are characterized by a vanishing net magnetic moment and a spin polarized electronic band structure.

In this talk, we introduce a model with altermagnetism in which the emergence of an anomalous Hall effect is driven by interactions.

This model is grounded in a modified Kane-Mele framework with antiferromagnetic spin-spin correlations.

Quantum Monte Carlo simulations show that the system undergoes a finite temperature phase transition governed by a primary antiferromagnetic order parameter accompanied by a secondary one of Haldane type. The emergence of both orders turns the metallic state of the system, away from half-filling, to an altermagnet with a finite anomalous Hall conductivity [1]. A mean field ansatz corroborates these results, which pave the way into the study of correlation induced altermagnets with finite Berry curvature.

[1] Sato et al., Phys Rev. Lett. 133, 086503 (2024)

標題：Emergence of a Fermi-surface in the current-driven Hidden state of 1T-TaS2
日時：2024 年 12 月 6 日(金) 午後 3 時
場所：物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：Amit Kanigel 氏
所属：Technion-Israel Institute of Technology
要旨：

We investigate the nature of the metallic metastable state in 1T-TaS2. Using micro-ARPES, we measure the spatially-dependent modifications of the electronic structure of the sample following a short current pulse. We observe that, in some regions of the sample, a Fermi surface emerges, while other regions remain gapped. A detailed study of the band structure in these different regions suggests that the metallic parts are in a state similar to the nearly commensurate charge density wave (NC-CDW) state, where the gaps are suppressed and a band crosses the Fermi level. Furthermore, we find that the metallic and insulating regions of the sample exhibit different dispersions normal to the planes. This observation is consistent with a scenario in which the current pulse breaks the star-of-David dimers present in the commensurate charge density wave (C-CDW) state.

標題：鉄系超伝導体 Fe(Se,Te)薄膜ヘテロ構造における超伝導ダイオード効果の観測
日時：2024 年 12 月 12 日(木) 午前 11 時～午後 0 時
場所：Online
講師：塩貝純一准教授
所属：大阪大学大学院理学研究科
要旨：

薄膜の表面・界面では、空間反転対称性の破れに起因する新奇な量子現象やスピン機能が発現する。

超伝導体を含む薄膜積層構造で観測される超伝導ダイオード効果はその好例である。この効果は量子磁束の非相反伝導現象に由来すると考えられるが、その起源については、構造の反転対称性の破れに起因するスピン軌道相互作用、試料構造のマクロな非対称性、試料内や試料端の非対称な欠陥等が提案されており、これまで様々な超伝導物質や試料構造を用いた研究が精力的に進められている。本セミナーでは、磁場中の超伝導臨界電流と高調波抵抗の二つの測定を通して、Fe(Se,Te)/FeTe 薄膜ヘテロ構造における超伝導ダイオード効果の起源について議論した。

標題：Tensor tree learns hidden relational structures in data to construct generative models
日時：2024 年 12 月 13 日(金) 午後 4 時～午後 5 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）
講師：原田 健自
所属：京都大学大学院　情報学研究科
要旨：

Generative modeling is a significant machine learning technique that constructs the probability distribution of a dataset, owing to its wide range of applications across various problems. Recently, there has been extensive research into generative modeling on quantum computers, referred to as Born machines [1-8]. This approach utilizes the output of projective measurement of quantum states for stochastic samplings.

We propose a general method for constructing a generative model based on the tree tensor network within the Born machine framework [9]. The core idea is to optimize the tree structure dynamically to minimize the bond mutual information. We demonstrate potential applications with four examples:

(1) Random bit sequences with long-range correlation
(2) Images of handwritten digits from the QMNIST dataset
(3) Bayesian networks
(4) Stock price fluctuations in the S&P 500

Our method significantly enhances performance and reveals hidden relational structures in the target data, paving the way for future improvements and advancements.

[1] Z.Y. Han, J. Wang, H. Fan, L. Wang, and P. Zhang. Physical Review X, 8, 031012 (2018).
[2] J.-G. Liu and L. Wang. Physical Review A, 98, 062324 (2018).
[3] M. Benedetti, D. Garcia-Pintos, O. Perdomo, V. Leyton-Ortega, Y. Nam, and A. Perdomo-Ortiz. npj Quantum Information, 5, 45 (2019).
[4] S. Cheng, L. Wang, T. Xiang, and P. Zhang. Physical Review B, 99, 155131(2019).
[5] B. Coyle, D. Mills, V. Danos, and E. Kashefi. npj Quantum Information, 6, 60 (2020).
[6] M. Benedetti, B. Coyle, M. Fiorentini, M. Lubasch, and M. Rosenkranz. Physical Review Applied, 16, 044057 (2021).
[7] M.S. Rudolph, J. Miller, D. Motlagh, J. Chen, A. Acharya, and A. Perdomo-Ortiz. Nature Communications, 14, 8367 (2023).

[8] M. Hibat-Allah, M. Mauri, J. Carrasquilla, and A. Perdomo-Ortiz. Communications Physics, 7, 68 (2024).
[9] K. Harada, T. Okubo, and N. Kawashima. arXiv:2408.10669 (2024).

標題：Quantum annealing of a programmable Ising spin glass
日時：2024 年 12 月 17 日(火) 午前 11 時
場所：物性研究所本館 6 階 第 2 セミナー室（A612）
講師：Prof. Anders W. Sandvik
所属：Boston University
要旨：

In quantum annealing, a system with two non-commuting time dependent interactions is slowly evolved from an initial trivial state to a final complex classical state. If the evolution is slow enough, the final state can represent the solution of a difficult optimization problem encoded in the Hamiltonian. I will discuss experiments [1] on the D-Wave Advantage device, which consists of more than 5000 superconducting qubits, here programmed to one of the prototypical hard optimization problems; the 3D Ising spin glass. While the coherence times are not long enough to reach the ground state of large systems, results for short annealing times, up to 40 ns, exhibit Kibble-Zurek scaling in the system size and annealing time, showing that the system traverses the spin glass transition with the expected critical exponents. This field is now at an inflection point, where quantum annealing can address some problems beyond the reach of classical computers [2].

[1] A. King et al., Nature 617, 61 (2023).
[2] A. King et al., arXiv:2403.00910.

標題：Low-dimensional magnetism
日時：2024 年 12 月 18 日(水) 午後 2 時～午後 3 時
場所：附属中性子科学研究施設 （東海村）及び Online（ハイブリッド開催）
講師：Ge Yuqing
所属：KTH Royal Institute of Technology
要旨：

I will give a presentation on my work during my PhD focused on low-dimensional magnetism including “quasi-2-dimenison(2D)” and “synthetic 2D” materials. The quasi-2D is about van der Waals (vdW) magnets who are nearly 2 dimensional with negligible interlayer interaction due to the weak vdW coupling, for example, the Chromium trihalide CrCl3, and the Vanadium trihalide VI3. On the other hand, for the synthetic 2D system, I was focusing on the skyrmion hosting Pt/Co40Fe40B20/Ru-based multilayers for its depth dependent static and dynamical properties.

2D magnets have raised large interests due to the potential of being applied to spintronics devices and their magnetic subtleness. Among a vast variety of these materials, CrCl3 features an A-type antiferromagnetic order with easy-plane magnetic anisotropy, giving rise to an XY model and prediction on its ability to host merons [1], whereas the VI3 manifests a Kitaev-type exchange interaction [2] and a rich magnetic-structural phase diagram under. Due to the vdW nature, they exhibit high sensitivity to external pressure. Therefore, we have carried out both ambient and high-pressure experiments on them with muon spin rotation (μ+SR) [3, 4, 5], also neutron powder diffraction (NPD) was performed on CrCl3.

The Pt/Co40Fe40B20(CFB)/Ru-based multilayers have been a typical model system for realization of interfacial

Dzyaloshinskii-Moriya interaction (DMI) [6] to stabilize Neel-type skyrmions. The heavy metal spacers inducing perpendicular anisotropy, DMI, and the interlayer exchange coupling between the CFB. Here, we used low energy μ+SR to study the magnetic fluctuations and revealed its 3 dimensionality beyond the toy-model of 2D point-like particles.

[1] Lu, Xiaobo, et al. Nat. Comm. 11.1 (2020): 4724.
[2] Gu, Yiqing, et al. Physical Review Letters 132.24 (2024): 246702.
[3] Forslund, Ola Kenji, et al. arXiv preprint arXiv:2111.06246 (2021).
[4] Ge, Yuqing, et al., in preparation.
[5] Forslund, Ola Kenji, et al. arXiv preprint arXiv:2210.17455 (2022).
[6] Moriya, Tôru. Physical review 120.1 (1960): 91.

標題：プラス帯電性マイクロ・ナノバブル水の特性と社会実装
日時：2024 年 12 月 19 日(木) 午前 10 時～午前 11 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）
講師：大平 猛
所属：東京大学物性研究所 原田研・大平開発ユニット
要旨：

最大径を nm（ナノメートル）レベルに有する閉鎖型気液界面は、ナノバブルの名称と共に単なる気泡以外の特徴が注目されています。当初ナノバブル自体の可視化が困難であったため、ナノバブルを間接証明する文献のみが先行し、目視可能な形でのナノバブル証明が無かったため、大多数のナノバブル効果がエビデンス無き評価として残されました。今回のセミナーでは、大平研究ユニットにて得られた知見としてナノバブルの実体解明法と計測された結果に基づき、ナノバブルと共に最大径がμm（マイクロメートル）レベルのマイクロバブルと共に、その存在維持・効果発揮の要件を整理し提示させて頂きたいと思います。また、同要件より従来技術で産生されるナノバブルの大半が無帯電性およびマイナス帯電性を示すのに対し、極めて生成が困難とされた純粋化され中性環でも生成可能なプラス帯電性ナノバブルと表現し得る微細気泡水の特性・機能を従来微細気泡との相違点を明らかにし、その斬新な効果と共に御提示させて頂きます。

最後に National Institute of Technology and Evaluation (Nite) による国際標準化として示されるウルトラファインバブルと帯電性ナノバブルの関係性および帯電性ナノバブルの社会実装の現状について御提示させて頂きました。

標題：On dynamic critical exponents of gapless frustration-free systems
日時：2024 年 12 月 20 日(金) 午後 4 時～午後 5 時
場所：Seminar Room 5 (A615), 6th Floor, ISSP and Online (Hybrid)
講師：Rintaro Masaoka
所属：Department of Applied Physics, The University of Tokyo
要旨：

Frustration-free systems are theoretically tractable quantum systems characterized by ground states that minimize all local terms in the Hamiltonian simultaneously. For gapped phases, frustration-free systems have been successful as models that approximate general systems. In contrast, for gapless systems, the assumption of frustration-freeness imposes significant constraints on their phase properties. While typical gapless systems exhibit an emergent Lorentz symmetry with a dynamic critical exponent , all known examples of gapless frustration-free systems satisfy . This suggests that frustration-freeness can be used to classify gapless quantum phases.

In this talk, we present a proof of for dynamic critical exponents for gapless frustration-free systems, assuming certain technical conditions on correlation functions. We will illustrate this result with several examples of gapless frustration-free systems, highlighting the implications of their anomalous dynamic critical exponents.

Additionally, we discuss the notable connection between frustration-free systems and Markov processes. It is known that Markov processes which describe standard relaxation to equilibrium states can be mapped onto frustration-free systems. The inequality , long recognized but unproven in non-equilibrium statistical physics, finds a rigorous foundation through our quantum framework.

標題：超短レーザー・X 線パルスを駆使した光誘起多自由度相関ダイナミクスの研究 / ナノ構造物質からの高次高調波発生: バンド内遷移とバンド間遷移

日時：2024 年 12 月 23 日(月) 午後 1 時～午後 3 時

場所：物性研究所本館 6 階 第 1 会議室 (A636) および Online (Hybrid)

講師：1. 深谷 亮 氏 2. 中川 耕太郎 氏

要旨：講師：深谷 亮 氏（板谷研究室 特任助教）

超短レーザー・X 線パルスを駆使した光誘起多自由度相関ダイナミクスの研究

【概要】

超短光パルスを利用した物性制御は、量子相転移に伴う巨視的かつ高速な応答性から、次世代の超高速スイッチングデバイスの動作原理や、光でのみ実現可能な新たな特性の創成につながることが期待されている。近年の物質科学や計測技術の発展に伴い、光の特性や物質の多自由度相関を積極利用した物性制御や、非平衡状態の結晶構造や電子秩序状態を超短 X 線・電子線パルスを利用して直接的に捉えることが可能となってきた[1]。本講演では、梯子型銅酸化物で発現するサブピコ秒絶縁体－金属双方向光スイッチング[2]と、放射光 X 線パルスの高繰返し発生特性を活かした時間分解 X 線計測技術[3]に関する研究を紹介した。

[1] S. Koshihara, R. Fukaya et al., Phys. Rep. 942, 1 (2022).
[2] R. Fukaya et al., Nat. Commun. 6, 8519 (2015).
[3] R. Fukaya et al., J. Synchrotron Rad. 29, 1414 (2022).

講師：中川 耕太郎 氏（松永研究室 特任研究員）

ナノ構造物質からの高次高調波発生：バンド内遷移とバンド間遷移

【概要】

高次高調波発生（HHG）はアト秒パルス発生や X 線光源などの応用に向けて注目される非線形光学現象である。近年では固体からの HHG が観測され[1]、特に電子のバンド内とバンド間での遷移によってその発生機構が理論的に議論されている。しかしながら、実験的にそれらの寄与を切り分ける研究は少ない。本講演では、ナノ物質であるナノ粒子とグラフェンに注目して、電子のバンド内遷移やバンド間遷移を制御し、HHG への寄与を解明した[2,3]。

[1] S. Ghimire et al., Nat. Phys. 7, 138 (2011).
[2] K. Nakagawa et al., Nat. Phys. 18, 874-878 (2022).
[3] K. Nakagawa et al., under review.

標題：Exploring novel superconducting and spintronic properties in few-layer Td-MoTe2
日時：2024 年 12 月 26 日(木) 午後 3 時～午後 4 時
場所：物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：若村 太郎
所属：NTT 物性科学基礎研究所
要旨：

Two-dimensional materials exhibit unique properties, particularly in the thin limit. Td-MoTe2 is a transition metal dichalcogenide known as a type-II Weyl semimetal in the bulk form. It becomes superconducting at low temperatures, but the low critical temperature (Tc) around 100 mK makes it difficult to investigate its superconducting properties for pursuing signatures of topological superconductivity. On the other hand, a significant enhancement of Tc has recently been reported by decreasing the thickness of Td-MoTe2, the origin of which remains unclear. Td-MoTe2 is also attractive in spintronics owing to the low crystal symmetry and strong spin-orbit interaction, which generate unconventional spin Hall effect and spin-orbit torques. While there exist many studies on electronic and spintronic properties of bulk Td-MoTe2, few-layer Td-MoTe2 has scarcely been explored due to the instability of the material in the atmosphere and experimental difficulties in the device fabrication.

In this talk, focusing on superconducting and spin transport properties, I will first show the thickness dependence of superconducting properties in few-layer Td-MoTe2, and discuss a possible pairing symmetry by comparing the experimental data with the first principles calculation results. Exploiting enhanced superconductivity and the low crystal symmetry, we successfully demonstrated the giant superconducting nonreciprocal transport driven by the ratchet-like motion of superconducting vortices, and the gate modulation of nonreciprocal signals by reducing the sample thicknesses [1, 2]. In the second part, I will introduce unique spintronic properties of Td-MoTe2, and present our recent results on spin transport revealed by weak antilocalization measurements in few-layer samples, where spin relaxation time is also gate tunable, and a factor of three variation is possible in the monolayer limit.

[1] T. Wakamura et al., “Gate-tunable giant superconducting nonreciprocal transport in few-layer Td-MoTe2” Phys. Rev. Research. 6, 013132 (2024).
[2] T. Wakamura et al., “Superconducting properties of few-layer Td-MoTe2”, submitted.

標題：UV complete field theory in (2+1)D with symmetry breaking at all temperatures
日時：2025 年 1 月 15 日(水) 午前 11 時～午後 0 時
場所：物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：Prof. Michael Scherer
所属：The Ruhr-Universität Bochum
要旨：

It was recently established that spontaneous symmetry breaking can persist at all temperatures in certain biconical vector models with coupled Ising and N-vector fields when the underlying field theories are ultraviolet complete, i.e., if they can be defined on all scales. So far, the existence of such models has only been explored in fractional dimensions for local but non-unitary models or in 2+1 dimensions but for non-local models. In my talk, I will discuss our study of local models at zero and finite temperature directly in 2+1 dimensions employing functional methods. At zero temperature, I show that our approach reproduces the critical behaviour with high accuracy for all N. I will then exhibit the mechanism of discrete inverted symmetry breaking for increasing temperature near the biconical critical point when N is finite but large. We calculated the corresponding full finite-temperature phase diagram and further

showed that the Mermin-Wagner-Hohenberg theorem is respected within this approach, i.e., symmetry breaking only occurs in the Ising sector. Finally, we also determined the critical value above which this phenomenon occurs to be N~15.

標題：強磁場下における偏光顕微観察装置の開発と応用
日時：2025 年 1 月 24 日(金) 午前 11 時～午後 0 時
場所：Online
講師：木下雄斗 特任助教
要旨：

磁場中における偏光顕微観察は、物性分野のみならず、生物、材料科学など幅広い分野への応用が期待される。一方で、磁場印加に用いるマグネットへの制約が大きく強磁場下における偏光顕微観察についてはそれほど行われてこなかった。我々は対物レンズを既存の強磁場印加用マグネット内の試料空間に直接挿入することで定常およびパルス強磁場中で偏光顕微観察可能な装置を開発した。また装置の拡張として長焦点レンズを利用した広視野における観察や磁気冷凍を用いた低温イメージング、圧力下イメージングなどにも取り組んでいる。講演では装置の概要と実際の観察結果について紹介した。

標題：超伝導接合における完全計数統計の理論
日時：2025 年 1 月 29 日(水) 午後 1 時～午後 2 時
場所：物性研究所本館 6 階 第 4 セミナー室（A614）
講師：田仲 由喜夫
所属：名古屋大学大学院
要旨：

電流の相関により生じるノイズは、メゾスコピック系を研究するための重要な情報を与え、コンダクタンスだけでは得られない知見を明らかにする。例えば、ノイズ測定は、従来の超伝導体の輸送キャリアが電荷 2e を持つことを示している[1]。既存の理論では、 従来型超伝導体のトンネル接合におけるゼロ温度ショットノイズに焦点が当てられており、そこでは準粒子とクーパー対のトンネル効果によって伝導特性が決定される。また電流の高次の相関の計算を可能とする完全係数統計の理論は従来型超伝導体接合に対して確立していた[2]。一方、非従来型超伝導体においては、通常の準粒子とクーパー対のトンネル効果に加えて第 3 のタイプの電荷輸送の担い手となる表面アンドレーエフ束縛状態（SABS）が存在する[3]。系を記述するハミルトニアンのトポロジカル不変量に由来する SABS を有する非従来型超伝導体はトポロジカル超伝導体となることが知られている[4,5]。

本発表では、非従来型超伝導体/常伝導金属接合における、完全係数統計の理論を紹介した[7]。この理論においては、SABS に加えて熱雑音がファノ因子（ノイズパワーの電圧微分とコンダクタンスの比）に及ぼす影響が自然に取り入れられているという特徴がある。SABS が分散をもたないフラットバンド零エネルギー状態になるか分散を有するかよって、ファノ因子の温度・電圧依存性に特徴的な違いが表れることが明らかになった[7]。

[1] Y. M. Blanter and M. Büttiker, Phys. Rep. 336, 1 (2000).
[2] W. Belzig and Y. V. Nazarov, Phys. Rev. Lett. 87, 067006 (2001).
[3] S. Kashiwaya and Y. Tanaka. Rep. Prog. Phys. 63, 1641 (2000).
[4] M. Sato, Y. Tanaka, K. Yada, and T. Yokoyama, Phys. Rev. B 83, 224511 (2011).
[5] Y. Tanaka, M. Sato, and N. Nagaosa, J. Phys. Soc. Jpn. 81, 011013 (2012).
[6] 超伝導接合の物理 田仲由喜夫(名古屋大学出版会)2021 年
[7] T. Kokkeler, A. Golubov, F.S. Bergeret, and Y. Tanaka, arXiv:2411.02011 (2024).

標題：Dynamics with Simultaneous Dissipations to Fermionic and Bosonic Thermal Reservoirs
日時：2025 年 1 月 31 日(金) 午後 4 時～午後 5 時
場所：物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：Arguelles Elvis Flaviano
所属：東京大学物性研究所
要旨：

Open systems evolve over time interacting with fermionic or bosonic reservoirs representing electrons in electrodes, lattice vibrations or electromagnetic fields. These reservoirs act as energy dissipation channels and sources of fluctuations that affect the dynamics. In electrochemical systems, the dynamics occurs under a moderate non-equilibrium condition influenced by a delicate balance of the multiple reservoirs. A critical property for characterizing such systems is the rate at which energy and charge are exchanged with the reservoirs, which can be investigated in principle using a microscopic-like theory based on the Langevin equation by incorporating the fluctuations and dissipation. The effect of multiple reservoirs, however, has received limited attention.

In this talk, we present a reformulation of the particle dynamics using the influence functional path integral [1] framework, which yields without phenomenological assumptions, a quasiclassical Langevin equation that incorporates non-Markovian effects of bosonic and fermionic reservoirs. As an example of the fermionic reservoir, we consider electrons in a metal electrode, where the dissipation of particle energy occurs via electron-hole pairs excitations giving rise to electronic friction. An explicit expression for the local dissipation kernel (Markovian kernel) is given in the limit of slow particle motion [2] providing a way to calculate the energy transfer rate through stochastic simulations. For demonstration purposes, we applied the framework to prototypical electrochemical systems [3] where a hydrogen (H) atom moves in contact with a metal electrode and solvent modes. We explore the interplay of the reservoirs using two scenarios: (1) quantum vibrational relaxation of a hydrogen (H) confined on a metal surface and (2) solvated electrochemical proton discharge.

[1] R. P. Feynman and F. L. Vernon, Ann. Phys. 24, 118 (1963).
[2] E. F. Arguelles and O. Sugino, J. Chem. Phys. 160, 144102 (2024).
[3] E. F. Arguelles and O. Sugino, in preparation.

標題：Spin pumping without quasiparticles
日時：2025 年 2 月 3 日(月) 午後 2 時～午後 3 時
場所：Seminar Room 5 (A615), 6th Floor, ISSP and Online
講師：Dr. Xiao-Tian Zhang
所属：University of the Chinese Academy of Sciences
要旨：

Spin pumping effect is a sensitive and well-established experimental method in two-dimensional (2D) magnetic materials. In this talk, we focus on the exotic case that strong interactions render Landau's quasiparticle not well-defined and the correlated system near a quantum critical point becomes a non-Fermi liquid(NFL) metal. We study the spin pumping effect of the NFL metal where the spin angular moments are not carried by any quasiparticles. We propose that spin pumping effect can be a valuable probe for NFL behaviors at the 2D interface of magnetic heterostructures. We show that the conventional Gilbert damping mechanism becomes invalid in the low-temperature regime, where it exhibits a power-law divergent ferromagnetic resonance (FMR) modulation; Whereas, at finite temperatures, Gilbert damping is restored. In both regimes, the non-quasiparticle nature of the NFL metal can be

extracted from experimentally measurable FMR modulation signals. If time allows, we will briefly mention our works on the NFL, including a novel type of NFL arises from a magnetic heterostructure, and more importantly, the strange metal transport that is relevant to the high-Tc cuprate superconductor and twisted bilayer graphene.

About the speaker:

Xiao-Tian Zhang (张啸天) earned his bachelor's degree from the College for Gifted Youngs at the University of Science and Technology of China in 2013. He then pursued his PhD at the International Center for Quantum Materials, Peking University, under the supervision of Prof. Ryuichi Shindou, graduating in 2019. From 2019 to 2022, he worked as a postdoc in Prof. Gang Chen's group at the University of Hong Kong. In 2022, he joined the Kavli Institute for Theoretical Sciences at UCAS, as a Director's Postdoctoral Fellow and Special Research Assistant (a.k.a. Assistant Researcher).

標題：Quantum impurity model for two-stage multipolar ordering and Fermi surface reconstruction
日時：2025 年 2 月 5 日(水) 午後 4 時～午後 5 時
場所：物性研究所本館 6 階　第 6 セミナー室（A615）
講師：Dr. SangEun Han
所属：Simon Fraser University, BC, Canada
要旨：

Classification and understanding of quantum phase transitions and critical phenomena in itinerant electron systems are outstanding questions in quantum materials research. Recent experiments on heavy fermion systems with higher-rank multipolar local moments provide a new platform to study such questions. In particular, experiments on Ce3Pd20(Si,Ge)6 show novel quantum critical behaviors via two consecutive magnetic field-driven quantum phase transitions. At each transition, the derivative of the Hall conductivity jumps discontinuously, which was attributed to sequential Fermi surface reconstructions. Motivated by this discovery, we consider an effective quantum impurity model of itinerant electrons coupled to local dipolar, quadrupolar, and octupolar moments arising from Ce3+ ions. Using renormalization group analyses, we demonstrate that two-stage multipolar ordering and Fermi surface reconstruction arise depending on which multipolar moments participate in the Fermi surface and which other moments are decoupled via Kondo destruction.

References:
1. Phys. Rev. B 108, L060401 (2023) (arXiv:2207.07661)

標題：Fascinating Molecular Nature of Organic Semiconductors – Photoconversion Driven by Molecular Structure and Orientation
日時：2025 年 2 月 6 日(木) 午前 11 時～午後 0 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）
講師：Prof. Ji-Seon Kim
所属：Department of Physics & Centre for Processable Electronics, Imperial College London, UK
要旨：

Organic semiconductors combine the semiconductor properties traditionally associated with inorganic materials with the more desirable properties of soft plastics. Moreover, the organic syntheses of these materials allow for great

flexibility in the tuning of their electronic and optical properties. In particular, the development of small molecule-based non-fullerene acceptors has enabled organic photoconversion devices such as photovoltaics and photodetectors to show remarkable improvements in device efficiency. Although promising, there is still a lack of fundamental understanding of the impact of molecular structure and orientation on photophysical processes critical for device performance.

In this talk, I will discuss the molecular perspectives of organic semiconductors for high performance photoconversion devices. First, I will show the molecular-structure dependent photostability, with a focus on molecular planarity, rigidity, and end groups [1, 2]. Second, I will show the molecular orientation-dependent energy level shifts, demonstrating the impact of molecular quadruple moments on thin film energetics and thereby on free charge generation [3-5]. Finally, I will discuss how the minor modification of sidechains affects the structural relaxation dynamics via strong electron phonon coupling and hence the excited states formation upon photoexcitation [6]. These results provide key fundamental understanding of molecular semiconductors.

References

[1] Luke et al., (2023) “Key molecular perspectives for high stability in organic photovoltaics”, NATURE REVIEWS MATERIALS, doi:10.1038/s41578-023-00606-5

[2] Luke et al., (2022) “Strong Intermolecular Interactions Induced by High Quadrupole Moments Enable Excellent Photostability of Non‐Fullerene Acceptors for Organic Photovoltaics”, ADVANCED ENERGY MATERIALS, 2201267. doi:10.1002/aenm.202201267

[3] Fu et al., (2023) “Molecular orientation-dependent energetic shifts in solution processed non-fullerene acceptors and their impact on organic solar cell performance”, NATURE COMMUNICATIONS, 14, 1870, doi:10.1038/s41467-023-37234-0

[4] Park et al., (2023) “The State-of-the-Art Solution-Processed Single Component Organic Photodetectors Achieved by Strong Quenching of Intermolecular Emissive State and High Quadrupole Moment in Non Fullerene Acceptors”, ADVANCED MATERIALS, doi:10.1002/adma.202306655

[5] Rana et al, (2024) “Octupole Moment Driven Free Charge Generation in Partially Chlorinated Subphthalocyanine for Planar Heterojunction Organic Photodetectors”, NATURE COMMUNICATIONS, 15(1), 5058. doi:10.1038/s41467-024-49169-1

[6] Pagano et al., (2024) “Slow vibrational relaxation drives ultrafast formation of photoexcited polaron pair states in glycolated conjugated polymers”. NATURE COMMUNICATIONS, 15(1), 6153. doi:10.1038/s41467-024-50530-7

標題：Spinon Singlet in Quantum Colored String: Origin of d-Wave Pairing in a Partially-Filled Stripe

日時：2025 年 2 月 7 日(金) 午後 2 時～午後 3 時

場所：物性研究所本館 6 階 第 5 セミナー室 (A615)

講師：Prof. Xuefeng Zhang

所属：Chongqing University

要旨：

Although both experimental observations and numerical simulations have reached a consensus that the stripe phase is intertwined with superconductivity in cuprates, the microscopic mechanism behind d-wave pairing in the presence of stripes remains unclear. Using the effective theory of quantum colored strings, we derive the wavefunction in Fock space. Our results show that two spinons with opposite chiralities tend to pair into a spinon singlet, which in turn facilitates the formation of negative pair-pair correlations between distant x-bonds and y-bonds, a hallmark of the d-

wave pairing pattern. The same pair-pair correlation pattern is observed across various models, as confirmed by large-scale density matrix renormalization group calculations. Based on these results, we conclude that the spinon singlet is the origin of d-wave superconductivity in a fluctuating, partially-filled stripe, and this mechanism may also extend to multi-stripe configurations.

Reference:
[1] arXiv:2412.04379
[2] arXiv:2406.01980

標題：多面体に基づく結晶構造デザイン
日時：2025 年 2 月 7 日(金) 午後 4 時～午後 5 時
場所：物性研究所本館 6 階 第 5 セミナー室（A615）及び ZOOM（Hybrid）
講師：横山 智康　氏
所属：パナソニック ホールディングス株式会社
要旨：

材料物性を決定する根源的なパラメータは、組成と構造である。組成設計は、ドーパント元素の選択や代替材料の開発など、多くの分野で成功を収めてきた。これは、周期表によって望ましい組成を特定できることに起因する。一方、構造設計、特に結晶材料における構造設計は、組成設計よりも難しい。このような困難は、イオン伝導性、誘電性、磁性など、結晶構造に強く影響される物性の理解を妨げている。

こうした現状を踏まえ、結晶構造設計の実現のためには、まず結晶構造における最小単位を定義する必要があると考え、それを多面体と定義した。なぜなら、結晶構造は周期的に繰り返される単位の集合体であり、各単位は空間を隙間なく埋め尽くす多面体の頂点に配置された原子で構成されているからである。金属結晶だけでなく、イオン結晶も多面体に基づいて考えることができる。負に帯電したアニオンから成り立つ構造をフレームワークとし、そのフレームワークを構成する多面体の中心サイトに正に帯電したカチオンが配置されている構造としてイオン結晶を捉えることができる。よって、元素を制御し組成をデザインするように、多面体を制御し結晶構造をデザインすることで、効率的な材料開発を実現できると考えた。

そこで本発表では、四面体に基づいたイオン伝導体の設計[1]と、グラフ理論による多面体から結晶構造生成[2]の二つの事例に関して紹介した。

[1] T. Yokoyama, et al., arXiv, 2407.02838 (2024).
[2] T. Yokoyama, et al., Cryst. Growth Des., 24 (2024) 2168–2178.