物性研究所セミナー

標題：Theory and simulations of the Orbital Rashba effect in FM/NM interfaces
日時：2025 年 11 月 21 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：PEZO LOPEZ Armando Arquimedes
所属：東京大学物性研究所
要旨：

Spintronics encounter challenges and inherent difficulties for manipulating quantum mechanical features in materials relying on specific properties. The recent discovery of the Orbital Hall effect lead to new proposals for manipulating the spin degree of freedom without heavy large-Z materials, in that sense, overcoming the scarcity of materials for developing new devices.

On the other hand, graphene still appears as a recurrent source of new physics mostly related to its particular electronic properties. In this talk, I'll give a short introduction of a new topic so-called Orbitronics whereby using numerical simulations we were able to disentangle spin and orbital-charge interconversion in Bi1-xSbx and Co/Al interfaces , I'll comment as well some ideas related to THz emission in Spintronics devices along with first principle calculations such heterostructures.

[1] H. Park et al., Topological Surface-Dominated Spintronic THz Emission in Topologically Nontrivial Bi1−xSbx Films. Adv. Sci. 2022, 9, 2200948

[2] E. Rongione et al., Spin-Momentum Locking and Ultrafast Spin-Charge Conversion in Ultrathin Epitaxial Bi1 − xSbx Topological Insulator. Adv. Sci. 2023, 10, 2301124.

[3] S. Rho et al., Exceptional Spin-to-Charge Conversion in Selective Band Topology of Bi/Bi1-xSbx with Spintronic Singularity. Adv. Funct. Mater., 33: 2300175.

[4] A. Pezo et al., Theory of spin and orbital charge conversion at the surface states of Bi1-x Sbx topological insulator.

[5] A. Pezo et al. Anatomy of torques from orbital Rashba textures: the case of Co/Al interfaces (https://arxiv.org/abs/2503.16319)

標題：Symmetry and Topology of Superconductors: Superconducting Nodes and High-throughput Diagnosis
日時：2025 年 11 月 28 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：Seishiro Ono
所属：Institute for Solid State Physics, University of Tokyo
要旨：

The determination of the symmetry properties of superconducting gaps has been a central issue in the study of unconventional superconductivity. Although fully resolving this question remains challenging, the presence of superconducting nodes and their topological characteristics is crucial for uncovering unconventional pairing. Several comprehensive databases of topological materials in the normal phases have been established, but there is no equivalent database for topological superconductors—primarily because detailed information on the pairing symmetries of real materials is still lacking.

Sidestepping this issue, we tackle an alternative problem: the predictions of topological and nodal superconductivity in materials for each possible pairing symmetries. In this talk, we first discuss a framework to comprehensively classify superconducting nodes pinned to any line in momentum space, which results in a complement of the symmetry-indicator theory. Next, we combine this classification with symmetry-indicator theory to demonstrate a systematic diagnosis of both topological and nodal superconducting states. Finally, we discuss recent progress in detecting topological features in superconductors using Fermi-surface formulas.

References
– S. Ono & K. Shiozaki, Phys. Rev. X 12, 011021 (2022)
– F. Tang, S. Ono, X. Wan, and H. Watanabe, Phys. Rev. Lett. 129, 027001 (2022)
– Z. Zhang, K. Shiozaki, C. Fang, S. Ono, arXiv:2407.20231

標題：Dichotomy of quantum integrability and its breakdown
日時：2025 年 12 月 5 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：山口 瑞樹
所属：東京大学大学院総合文化研究科広域科学専攻
要旨：

In quantum many-body systems, the presence or absence of local conserved quantities is a key factor that governs thermalization and other dynamical properties. Empirically, one expects the following "integrability dichotomy" for quantum chains with nearest-neighbour interactions: A system is either (a) completely integrable, with k-local conserved quantities for all integers $k \geqq 3$, or (b) nonintegrable, with no nontrivial local conserved quantities at all; there is no intermediate case. Although this dichotomy is an important statement both theoretically and for applications, a rigorous proof has long been lacking.

In this talk I present three recent results towards a rigorous understanding of this dichotomy.

(i) For parity-symmetric spin-1/2 chains, we prove the dichotomy and show that all completely integrable models in this class are exhausted by the previously known examples.

(ii) For general SU(2)-invariant spin chains, we again establish the dichotomy and demonstrate that complete integrability versus nonintegrability is decided by a simple check of the Reshetikhin condition.

(iii) For bosonic chains with symmetric hopping and general on-site terms including non-Hermitian contributions, we uncover a breakdown of the dichotomy in the non-Hermitian regime via a complete classification of local conserved quantities. We find models that are almost nonintegrable but possess a single 3-local conserved quantity, as well as models that are nearly completely integrable yet lack a 4-local conserved quantity.

These results raise broader questions: Where is the boundary between regimes where the integrability dichotomy holds and where it breaks down? And what principles govern quantum many-body systems beyond the dichotomy? Clarifying these issues is an important direction for future work.

[1] M. Yamaguchi, Y. Chiba, and N. Shiraishi, *Complete Classification of Integrability and Non-integrability for Spin-1/2 Chain with Symmetric Nearest-Neighbor Interaction*, arXiv:2411.02162.

[2] N. Shiraishi and M. Yamaguchi, *Dichotomy Theorem Separating Complete Integrability and Non-integrability of Isotropic Spin Chains*, arXiv:2504.14315.

[3] M. Yamaguchi and N. Shiraishi, in preparation.

標題：From Monopole Paradox to Perfect Transmission: How to convert particles through defects
日時：2025 年 12 月 8 日(月) 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：上田 篤
所属：ゲント大学 物理・天文学科
要旨：

What happens when a charged chiral fermion interacts with a monopole? This fundamental question has arisen within the standard model. Callan discovered that what bounces back is not the original fermion but rather a particle that sometimes has a fractional charge, suggesting a fraction of electrons. This paradox, known as the "monopole paradox," has long posed interpretative challenges. Recently, a series of works have made progress on this topic, showing that the scattered particle can be viewed as a chiral fermion dressed with a topological string attached to the monopole. This string brings the fermion into the twisted sector, resulting in a fractional charge. This serves as a compelling example in field theory. But what about on the lattice?

In this talk, I will introduce analogous cases in condensed matter physics. When a pair of dual theories is coupled, we can design the interaction at the interface that exhibits perfect transmission for any wave packet. The particle that passes through the interface appears quite different from the original, as it is essentially disguised by a topological line. I will demonstrate a generic yet straightforward method to construct these models using matrix product unitaries and conclude by discussing the implications for some applications and the monopole paradox.

[1] C. G. Callan, Jr., Disappearing Dyons, Phys. Rev. D 25, 2141 (1982).

[2] M. van Beest, P. Boyle Smith, D. Delmastro, Z. Komargodski, and D. Tong, Monopoles, scattering, and generalized symmetries, JHEP 03, 014, arXiv:2306.07318.

[3] V. Loladze, T. Okui, and D. Tong, Dynamics of the Fermion-Rotor System (2025), arXiv:2508.21059.

[4] V. Loladze and T. Okui, Monopole-fermion scattering and the solution to the semiton–unitarity puzzle, Phys. Rev. Lett. 134, 051602 (2025).

[5] M. van Beest, P. Boyle Smith, D. Delmastro, R. Mouland, and D. Tong, Fermion-monopole scattering in the Standard Model, JHEP 08, 004, arXiv:2312.17746.

[6] A. Ueda, V. V. Linden, L. Lootens, J. Haegeman, P. Fendley, and F. Verstraete arXiv: 2510.26780.

標題：Symmetry Spans and Enforced Gaplessness
日時：2025 年 12 月 8 日(月) 午後 4 時 15 分～午後 5 時 15 分
場所：物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：安藤 貴政
所属：京都大学 基礎物理学研究所
要旨：

Global symmetry is often useful in specifying ground states of quantum many-body systems; some symmetries forbid unique gapped ground states via anomaly-matching arguments, also known as Lieb–Schultz–Mattis type constraints. However, ruling out any gapped ground states, including degenerate ones, is significantly harder. Although anomalies of continuous symmetries can exclude such phases, realizing these anomalous symmetries exactly on lattices with finite-dimensional on-site Hilbert spaces is presumably impossible.

In this talk, we propose a different (but likely related) approach to exclude all gapped ground states in one spatial dimension. Specifically, we study situations where two different symmetries share a common symmetry—for example, where the two symmetries are non-invertible or continuous, and the common one is a non-anomalous group symmetry. We argue that such configurations, which we call symmetry spans, can forbid gapping. We clarify the argument for symmetry spans and gaplessness and illustrate it through concrete examples.

This talk is based on ongoing work with Kantaro Ohmori (RIKEN iTHEMS).

標題：有機導体で実現する質量ゼロのディラック電子系：発見から最近の新展開まで

日時：2025 年 12 月 9 日(火) 午後 2 時～

場所：Online 及び物性研究所本館 6 階 第 5 セミナー室（A615）

講師：田嶋 尚也

所属：東邦大学理学部物理学科

要旨：

グラフェンの発見から約 20 年。質量ゼロのディラック／ワイル電子は、いまや多くの物質において実現しうる電子状態として広く認知されるようになった。光錐状の特異な分散（ディラックコーン）が上下で突き合わさり、「点」（ディラック点）で接することで電子質量がゼロとなる。この幾何学がもたらす物理は、凝縮系物理の重要なテーマである。

その中でも、有機導体 α-(BEDT-TTF)2I3 は世界で初めてバルク系で質量ゼロディラック電子を実現し、フェルミ準位がディラック点に一致するという他の物質が敵わない特徴を備えている[1,2,3]。一方で、この物質は常圧・低温では電荷秩序を伴う絶縁体だが、静水圧の印加により質量ゼロのディラック電子系へと"量子相転移"する。電子相関の強さを圧力制御できる点も、この系の魅力の一つである。

本講演では、質量ゼロディラック電子系 α-(BEDT-TTF)2I3 がどのように発見に至ったのかを振り返りつつ、ディラック「点」が生み出す多彩な物理、ディラック点がどのように"不安定化"するのかについて、姉妹物質 α-(BETS)2I3 を含め輸送現象を中心に紹介した[2-8]。さらに近年、この系は新たな局面を迎えつつあり、カイラル対称性の破れを伴う 3 次元ディラック半金属状態が低温で実現することも明らかになってきた[9, 10]。本講演では、この量子異常に起因する輸送特性についても最新の結果を交えて論じた。

参考文献

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[2] K. Kajita, et al., J. Phys. Soc. Jan. 83, 072002 (2014).

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[4] T. Osada, J. Phys. Soc. Jpn. 77, 084711 (2008).

[5] N. Tajima, Phys. Rev. Lett. 102, 176403 (2009).

[6] Y. Unozawa, et al., J. Phys. Soc. Jpn. 89, 2137902 (2020).

[7] Y. Kawasugi, et al., Phys. Rev. B 103, 205140 (2021).

[8] K. Iwata, et al., J. Phys. Soc. Jpn. 92, 053701 (2023).

[9] T. Morinari, J. Phys. Soc. Jpn. 89, 073705 (2020).

[10] N. Tajima, et al., J. Phys. Soc. Jpn., 92, 123702 (2023).

標題：微細加工と強磁場実験の協奏による新たな物性研究に向けて
日時：2025 年 12 月 12 日(金)　午前 11 時～午後 0 時
場所：Online
講師：橋坂 昌幸 准教授
所属：物性研究所
要旨：

微細加工による物質の整形・素子化は、物質が本来もつミクロスコピックな物性を抽出し、その本質に迫るための極めて強力なアプローチである。東大物性研の量子物質ナノ構造ラボ（量子ナノラボ）では、微細加工を核として、物質開発と大型施設における先端計測を結びつける研究手法の開拓を進めている。本講演では、まず自己紹介を兼ねて、私がこれまで取り組んできた半導体量子輸送の研究を概説した。その後、量子ナノラボで現在進めている微細加工を基盤とした量子物質の研究を紹介し、今後の展望について述べた。微細加工技術と大型強磁場施設における実験を組み合わせることで、どのような新しい物性研究が可能になるのか――その可能性を皆さまと議論するきっかけとなれば幸いである。

標題：TensorMC: Markov-Chain Monte Carlo in Tensor-Network Representation
日時：2025 年 12 月 12 日(金) 午後 2 時～午後 3 時
場所：Online **及び物性研究所本館 6 階 第 5 セミナー室 (A615)**
講師：Synge Todo
所属：Department of Physics, The University of Tokyo
要旨：

Markov chain Monte Carlo (MCMC) is a powerful tool for sampling from complex probability distributions. Despite its versatility, MCMC often suffers from strong autocorrelation and the negative sign problem, leading to slowing down the convergence of statistical errors. We propose a novel MCMC formulation based on tensor network representations to reduce the population variance and mitigate these issues systematically. By introducing stochastic projectors into the tensor network framework and employing Markov chain sampling, our method eliminates the systematic error associated with low-rank approximation in tensor contraction while maintaining the high accuracy of the tensor network method. We demonstrate the effectiveness of the proposed method on the two-dimensional Ising model, achieving an exponential reduction in statistical error with increasing bond dimension cutoff. Furthermore, we address the sign problem in systems with negative weights, showing significant improvements in average signs as bond dimension cutoff increases. We also show that the present framework can naturally be extended to sequential Monte Carlo (SMC).

References
[1] S. Todo,“Markov Chain Monte Carlo in Tensor Network Representation,”arXiv:2412.02974.

標題：Local shot-noise on superconductors
日時：2025 年 12 月 16 日(火) 午後 3 時～
場所：Online 及び物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：Dr. Yudai Sato
所属：Faculty of Physics, Ludwig-Maximilians-University of Munich, Munich, Germany & Leiden Institute of Physics, Leiden University, Leiden, The Netherlands
要旨：

Shot noise in tunneling experiments reflects the Poissonian nature of charge transport, with the noise power directly proportional to the current and the effective charge of the tunneling carriers. This relation provides a powerful spectroscopic tool to probe electron pairing phenomena in superconductors [1, 2]. In this talk, I will report on two distinct applications of local shot-noise measurements using scanning tunneling microscopy to explore superconducting states.

First, I will present our shot-noise measurements on the cuprate high-Tc superconductors, $Bi_2Sr_2Ca_2Cu_1O_{8+p}$, where a pseudogap state is observed. The origin of the pseudogap has long been debated, with hypotheses involving either precursor electron pairing or competing local orders. Our local noise measurements reveal that the pseudogap energy is associated with electron pairing [3], up to more than 70meV.

Second, I will present our results of multiple Andreev reflections (MAR). MAR processes in superconductor−insulator−superconductor (SIS) junctions involve successive Andreev reflections, resulting in the transfer of an effective charge ne [4]. We succeeded to measure MAR noise of an SIS junction on a Pb(111) surface by using a superconducting tip.

References
[1] Y. M. Blanter and M. Büttiker, Shot noise in mesoscopic conductors. Physics Reports, 336, 1 (2000).
[2] K. M. Bastiaans, D Cho, et al., Direct evidence for Cooper pairing without a spectral gap in a disordered superconductor above Tc, Science 374, 608 (2021).
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[4] T. M. Klapwijk, G. E. Blonder, and M. Tinkham, Physica (Amsterdam) 109B & 110B, 1657 (1982).

標題：Listening to the sound of superfluid
日時：2025 年 12 月 17 日(水) 午後 4 時 30 分～午後 5 時 20 分
場所：物性研究所本館 6 階 第 5 セミナー室 (A615)
講師：Kin Chung Fong
所属：Northeastern University
要旨：

The exploration of unconventional superconductivity has entered a new frontier with the emergence of exotic phases in quantum materials—from moiré superlattices to topological semimetals. Probing the superfluid properties and pairing symmetry in these systems is essential to understanding their unconventional behavior, yet traditional techniques often falter when applied to atomically thin materials or those with extremely low critical temperatures. Here, we present a novel approach that "listens to the sound of superfluid" by probing the kinetic inductance of superconductors through microwave resonant cavities. Variations in superfluid stiffness perturb the cavity resonance frequency, enabling precise measurements of the London penetration depth with parts-per-million sensitivity. This technique provides unprecedented access to the superfluid response in fragile and low- temperature superconductors. Applied to magic-angle twisted trilayer graphene and the Weyl semimetal $MoTe_2$, our measurements uncover compelling signatures of nodal superconductivity. In twisted trilayer graphene, we observe a linear temperature dependence of the superfluid stiffness and a zero-temperature stiffness that scales linearly with the critical temperature—echoing Uemura's relation in cuprates. In $MoTe_2$, the penetration depth exhibits a T 2 dependence down to millikelvin temperatures. Most strikingly, both systems display the anomalous nonlinear Meissner effect, where the superfluid response becomes current- dependent—a hallmark of nodal quasiparticles. These results offer strong evidence for unconventional pairing in both moiré and topological superconductors, demonstrating how "listening" to the subtle resonances of quantum fluids can illuminate the hidden symmetries of correlated electron matter.

Ref.: A. Banerjee, et. al., Nature 638, 93 (2025).
Contact: Miuko Tanaka miukot@issp.u-tokyo.ac.jp

標題：Exotic spin states in new Ti3+ based quantum kagome antiferromagnets
日時：2025 年 12 月 19 日(金) 午前 9 時 30 分～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：Prof. Seunghun Lee
所属：The University of Virginia, USA
要旨：

The pursuit of quantum spin liquid (QSL) states in condensed matter physics has drawn attention to kagome antiferromagnets (AFM) where a two-dimensional corner-sharing network of triangles frustrates conventional magnetic orders. While quantum kagome AFMs based on Cu^{2+} ($3d^9$, s = 1/2) ions have been extensively studied, there is so far little work beyond copper-based systems. Recently, several new kagome compounds were discovered where Ti^{3+} (d^1) forms the spin 1/2 and F^- is the superexchange mediating ligand.[1] In this talk, we will discuss our recent studies, using bulk property and neutron scattering measurements, on single crystals of $Cs_8RbK_3Ti_{12}F_{48}$ [2] and $Cs_8LiNa_3Ti_{12}F_{48}$ [3].

References:
[1] Goto, M., Ueda, H. et al. Various disordered ground states and 1/3 magnetization-plateau-like behavior in the S = 1/2 Ti^{3+} kagome lattice antiferromagnets $Rb_2NaTi_3F_{12}$, $Cs_2NaTi_3F_{12}$, and $Cs_2KTi_3F_{12}$. Phys. Rev. B 94, 104432 (2016).
[2] Thennakoon, A., Yokokura, R., Yang, Y. et al. Gapless dispersive continuum in a modulated quantum kagome antiferromagnet. Nat Commun 16, 3939 (2025).
[3] Unpublished

標題：銅酸化物超伝導体の光誘起ジョセフソンプラズマ
日時：2025 年 12 月 22 日(月) 午後 3 時 30 分～午後 4 時 30 分
場所：物性研究所本館 6 階 第 2 セミナー室 (A612)
講師：西田 森彦
所属：Max Planck Institute for the Structure and Dynamics of Matter
要旨：

銅酸化物超伝導体は常温常圧下で最も高い超伝導転移温度を示す物質として、その座を 40 年近く守り続けているが、その超伝導発現機構については未解明な部分も多く、特に相図上に現れる種々の秩序相との関連においては統一的な理解

が得られていないのが現状である。そんな中、銅酸化物に対して超短パルスレーザーを照射することによって超伝導が誘起・増強されるという、いわゆる「光誘起超伝導」とよばれる現象が報告されてきた。本発表ではこの現象について、ジョセフソンプラズマ共鳴とよばれる銅酸化物超伝導体特有の現象を利用した実験結果を中心に紹介し、ランタン系・イットリウム系という 2 つの銅酸化物における「光誘起超伝導」の比較を通して、銅酸化物の秩序相と超伝導の関係性を議論した。

標題：Non-Adiabatic Excited-State Time-Dependent GW (TDGW) Molecular Dynamics: A New Possible Paradigm for Accurately Traversing The Excited-State Dynamical Landscape

日時：2025 年 12 月 24 日(水) 午後 4 時～午後 5 時

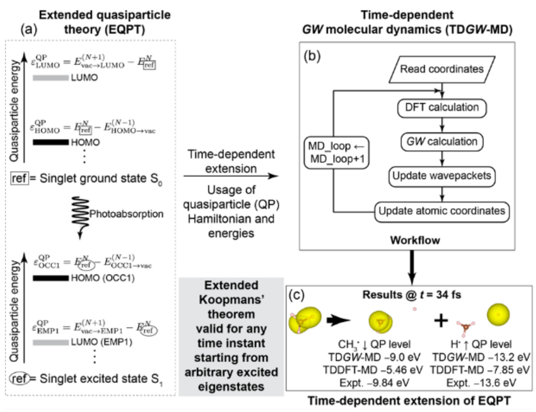
場所：Online **及び物性研究所本館 6 階 第 5 セミナー室**（A615）

講師：マンジャナス アーディチャ

所属：国立研究開発法人物質・材料研究機構（NIMS）

要旨：

Time-dependent density functional theory molecular dynamics (TDDFT-MD) [1] is the usual workhorse for studying excited-state (ES) dynamics, since it is computationally inexpensive. However, TDDFT-MD inevitably relies on adiabatic local density approximation (ALDA) [2], which is valid only for the initial state being the ground state and not for any initially excited state such as in photochemical reactions. Therefore, the results obtained with TDDFT-MD based on ALDA may be unreliable. The extended quasiparticle theory (EQPT) [3] has been shown to completely solve this problem. It guarantees the applicability of the GW approximation to any excited eigenstate as the initial reference state, contrary to conventional wisdom in the GW community. We have recently developed for the first time, a non-adiabatic dynamics methodology based on EQPT known as time-dependent GW molecular dynamics (TDGW-MD) to overcome the problem of ALDA for ES dynamics [4]. TDGW-MD exactly satisfies extended Koopmans’ theorem [5] and scales as ~O(NB3-4), NB − number of basis functions, which is distinctly advantageous to performing dynamics using configuration interaction. In the poster, I will show the mechanisms of important photochemical reactions using TDGW-MD, such as (a) the photolysis of methane [4, 6] as well as (b) the ring-opening mechanism in oxirane, as a way to demonstrate how TDGW-MD can be a major step towards traversing the excited-state dynamical landscape accurately.



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標題：Ferro-spinetic Altermagnets from Electronic Correlation
日時：2025 年 12 月 25 日(木) 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：佐藤 年裕 氏
所属：IFW Dresden
要旨：

Altermagnets are fully compensated antiferromagnets that lack the combined time-reversal and translation symmetry. We show that their symmetry allows for a switchable ferro-spinetic polarization − the spin analogue of erroelectricity − in a direction dictated by the lattice symmetry. We demonstrate this effect in its purest form in an interacting altermagnetic fermion model, in which a many-body chiral symmetry forbids any charge polarization. Our quantum Monte Carlo simulations reveal edge-localized, reversible spin accumulations fully consistent with this symmetry locking. Additionally, we identify Mn-based metal-organic frameworks as realistic hosts for the ferro-spinetic altermagnetic effect.

標題：第 1 回 ISSP-IMSS 研究会「レーザー、放射光、陽電子ビームの融合による物質・生命科学の新展開」
日時：2026 年 1 月 5 日(月) 午前 10 時～午後 4 時 50 分
場所：Online **及び物性研究所本館 6 階 大講義室**（A632）
要旨：

東京大学物性研究所(ISSP)と KEK 物質構造科学研究所(IMSS)は、複数の量子ビームを用いた物質・生命科学研究を進めている。両機関が持つ最先端の研究資源を融合させることで、物質・生命科学研究のフロンティアを切り開くための協力連携体制をスタートさせる。そのキックオフとなる第 1 回 ISSP-IMSS 研究会は、軟 X 線と硬 X 線の同時利用を可能にする新ビームラインの建設を PF、ISSP-SOR 両施設と共同で進めてきた UVSOR、HiSOR、およびこれら 4 施設の利用者の参加のもと、ISSP が有するレーザー・放射光技術、IMSS の強みである放射光・陽電子ビーム技術を用いた最新の研究成果と技術開発の状況を共有し、共創体制の構築と人的交流の促進を通じて、将来的に大きな成果が期待できる研究シーズを創出することを目的とした。

標題：Controlled bond expansion: a rank-adaptive approach for single-site DMRG and TDVP
日時：2026 年 1 月 7 日(水) 午後４時～
場所：Onlie
講師：Jheng-Wei Li
所属：CEA Grenoble
要旨：

Traditional single-site density matrix renormalization group (DMRG) does not allow bond expansion; multi-site DMRG does but at much higher computational costs. For matrix product states (MPS), we present a controlled bond expansion (CBE) algorithm that yields two-site accuracy at single-site costs.

Given an MPS, $¥Psi$, with a confined variational space, CBE explores its orthogonal subspaces and finds components carrying significant weight in $H ¥Psi$ to enrich it. This CBE approach in contrast with the previous perturbative expansion approaches is fully variational. Moreover, to simulate quantum dynamics using the time-