Winter School of the

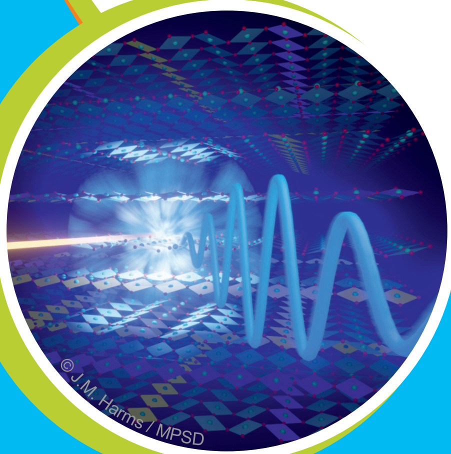
IMPRS-CMS, IMPRS-CPQM & MPI-UBC-UTokyo Center

T_C on the rise — Novel Trends in Superconductivity

December 3–6, 2024

Max Planck Institute for Solid State Research
Stuttgart, Germany

Program Details



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IMPRS for Condensed Matter Science
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IMPRS-CPQM

MAX PLANCK INSTITUTE FOR SOLID STATE RESEARCH

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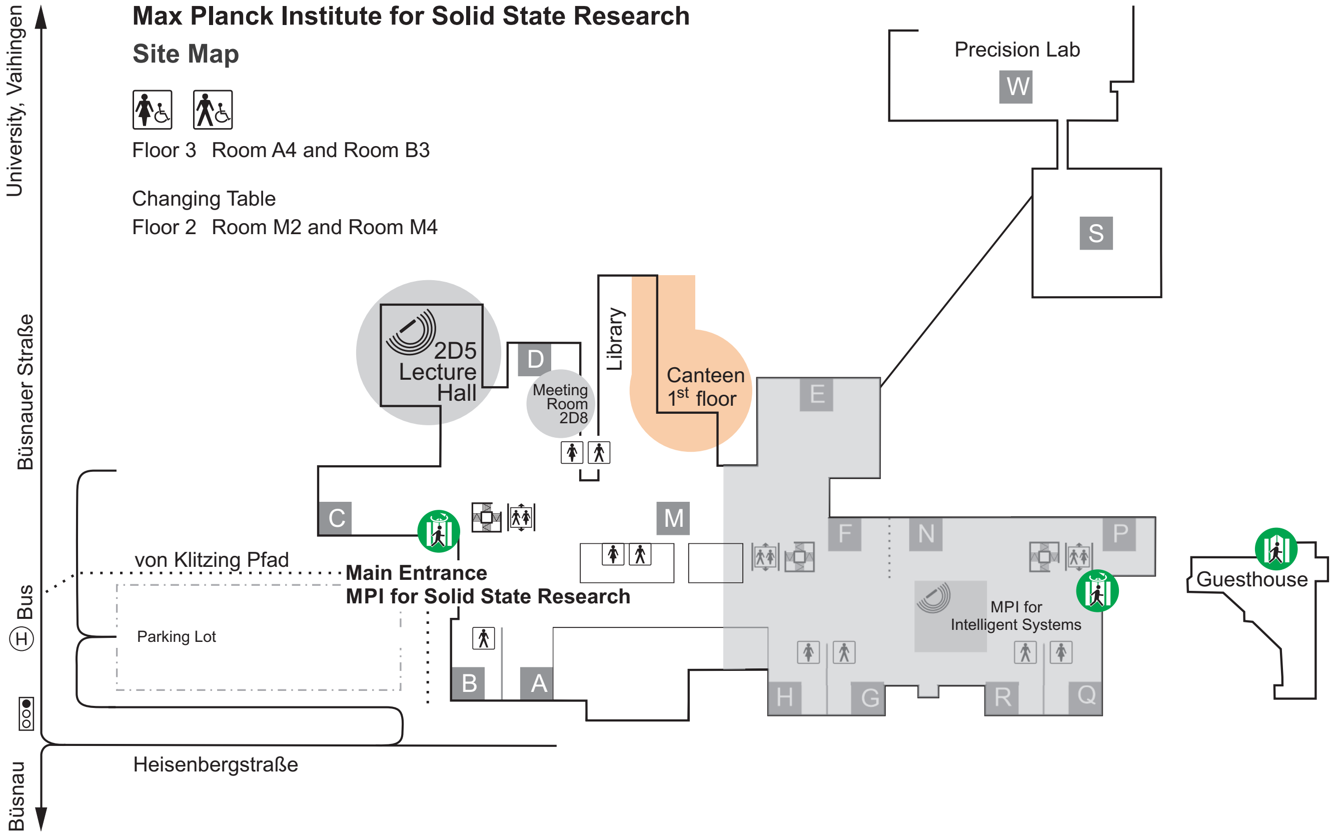
東京大学 THE UNIVERSITY OF TOKYO

Max Planck Institute for Solid State Research

Site Map

Floor 3 Room A4 and Room B3

Changing Table
Floor 2 Room M2 and Room M4



Scope

More than a hundred years after its discovery, superconductivity continues to fascinate researchers around the world, not least because of its great potential for applications. However, resistance-free current transport and perfect diamagnetism are only practical near room temperature. Therefore, the search for superconductivity with ever-higher transition temperature T_C remains at the forefront of research efforts.

In this Winter School we bring together experts in the field to learn how superconductivity can be explained by the Bardeen-Cooper-Schriefer theory and what makes some superconductors unconventional or topological. Our speakers will show in which materials superconductivity has been discovered so far, what they have in common and what makes them different. They will provide insights into how experiments reveal unique properties, how hydrides become superconducting at room temperature and high pressure, how laser pulses can induce transient superconducting states, and how the magnetic properties of superconductors can be exploited in future applications.

Tuesday, December 3rd, 2024
Program • Lecture Hall 2D5

08:00	**Registration**
9:15 – 9:30	**Welcome**
9:30 – 11:30	**Introductory Lecture** **Manfred Sigrist** ETH Zurich, Switzerland **Introduction to Superconductivity**
11:30 – 12:00	Coffee Break
12:00 – 13:00	**Lecture** **Thomas Schäfer** MPI for Solid State Research, Stuttgart, Germany **Theory of Unconventional Superconductivity: Cuprates and Nickelates**
13:00 – 14:00	Lunch
14:00 – 14:30	**Scientific Discussion**
14:30 – 15:30	**Lecture** **Matthias Scheurer** University of Stuttgart, Germany **Superconductivity due to and in spite of Magnetism**
15:30 – 16:15	Coffee Break
16:15 – 17:30	**Colloqium** **Marcel Franz** University of British Columbia, Vancouver, Canada **Topological superconductivity in twisted double-layer high- T_c cuprates: Theory, experimental signatures and applications**
17:30 – ...	**Welcome Dinner in the canteen**

Wednesday, December 4th, 2024
Program • Lecture Hall 2D5

9:30 – 11:30	**Introductory Lecture** **Hidenori Takagi** MPI for Solid State Research, Stuttgart & The University of Tokyo, Japan **Materials and mechanisms of superconductivity – How many roads to high-T_c ?**
11:30 – 12:00	Coffee Break
12:00 – 13:00	**Lecture** **Mona Berciu** University of British Columbia, Vancouver, Canada **Bipolaronic high-temperature superconductivity**
13:00 – 14:00	Lunch
14:00 – 14:30	**Scientific Discussion**
14:30 – 15:30	**Lecture** **Eva Zurek** University at Buffalo, New York, USA **Computational Discovery of Conventional Superconductors**
15:30 – 16:00	Coffee Break
16:00 – 17:00	**Lecture** **Audrey Grockowiak** IFW Dresden, Germany **An Experimental View on Superconductivity in the Superhydrides**
17:00 – ...	**Poster Session + Finger Food in Entrance Hall**

Thursday, December 5th, 2024
Program • Lecture Hall 2D5

9:30 – 10:30	Lecture **Sven Friedemann** University of Bristol, UK **Electronic and Structural Reconstructions in high-pressure Superconductors**
10:30 – 11:00	Coffee Break
11:00 – 12:00	Lecture **Tabea Arndt** KIT, Karlsruhe, Germany **Unique selling points of (high temperature) superconducting magnets and novel trends**
12:00 – 12:30	**Scientific Discussion**
12:30 – 13:30	Lunch
13:30 – 14:30	Lecture **Daniele Nicoletti** MPI for the Structure and Dynamics of Matter, Hamburg, Germany **Recent Advances in the Optical Control of Superconductivity**
14:30 – 15:00	Coffee Break
15:00 – 16:00	Lecture **Andrea Damascelli** University of British Columbia, Vancouver, Canada **Probing condensates' coherence by TR-ARPES**
16:00 – 16:30	Coffee Break
16:30 – 17:30	**Lab Tour**
18:30 – ...	**Speakers' Dinner** Dinner at a local downtown restaurant

Friday, December 6th, 2024
Program • Lecture Hall 2D5

9:30 – 10:30	**Lecture** **Andrew Mackenzie** MPI for Chemical Physics of Solids, Dresden, Germany **When is a phase diagram not a diagram? Lessons learned from Sr_2RuO_4**
10:30 – 11:00	Coffee Break
11:00 – 12:00	**Lecture** **Hilary Noad** MPI for Chemical Physics of Solids, Dresden, Germany **Elastic tuning of unconventional superconductors**
12:00 – 12:30	**Scientific Discussion**
12:30 – 13:30	Lunch
13:30 – 14:30	**Lecture** **Andreas Schnyder** MPI for Solid State Research, Stuttgart, Germany **Topological Superconductors: From classification to recent examples**
14:30 – 15:00	Coffee Break
15:00 – 16:00	**Lecture** **Ryo Shimano** The University of Tokyo, Japan **Higgs spectroscopy in superconductors**
16:00 – 16:30	**Closing remarks**

Poster Overview

P-1	**Acharya**, Shakti Shankar Ravenshaw University, India	Ground State Anomaly in Invar Alloy
P-2	**Allen**, Portia MPI for the Structure and Dynamics of Matter, Hamburg, Germany	Quantum oscillations in focused ion beam microstructures of ZrSiS
P-3	**Dolgner**, Jakob MPI for Solid State Research, Stuttgart, Germany	Functional Non-equilibrium QFT as a tool for out-of-equilibrium phonon interactions in driven bilayer graphene
P-4	**Dutt**, Ravi Banaras Hindu University, India	Exciton Metal-Insulator Transition in CVD grown 2D disordered monolayer $MoSe_2$
P-5	**Emminghaus**, Anahita University of Stuttgart, Germany	Electrochemical Intercalation of VSe_2
P-6	**Forni**, Paulo MPI for Solid State Research, Stuttgart, Germany	Spin susceptibility in the pseudogap from a fluctuating spiral state
P-7	**García-Page**, Ana MPI for Solid State Research, Stuttgart, Germany	Chiral Quantum Phase Transition in Moiré Dirac Materials
P-8	**Heinsdorf**, Niclas MPI for Solid State Research, Stuttgart Germany & UBC Vancouver, Canada	Quasi-Particle Residues in Trilayer Cuprate
P-9	**Herrmann**, Dorothee MPI for the Structure and Dynamics of Matter, Hamburg, Germany	Design and characterization of a probe stick for high-frequency transport experiments in a cryogenic environment
P-10	**Jin**, Haolin MPI for Chemical Physics of Solids, Dresden, Germany	Exploring van der Waals cuprate superconductors using a hybrid microwave circuit
P-11	**Kamboj**, Rajat MPI for Solid State Research, Stuttgart, Germany	Inorganic electrides new arena of correlated electron physics
P-12	**Kulkarni**, Vinayak M. JNCASR Bangalore, India	A New State Of Laser Driven Interacting Impurities in Dirac Like Electrons Bath
P-13	**Leon**, Jaime MPI for Chemical Physics of Solids, Dresden, Germany	Fabricating Superconducting Constrictions on Sr_2RuO_4
P-14	**Maiti**, Ayanesh MPI for Chemical Physics of Solids, Dresden, Germany	*h/2e* oscillations in clean cuprate microstructures
P-15	**Meixner**, Michael MPI for Solid State Research, Stuttgart, Germany	Spatio-temporal fluctuations in strongly correlated quantum matter: from real space flucutations to spectral functions

Poster Overview

P-16	**Müller-Groeling**, Henrik MPI for Solid State Research, Stuttgart, Germany	*SU*(2) gauge theory of fluctuating stripe order in the two-dimensional Hubbard model
P-17	**Neri**, Silvia MPI for Solid State Research, Stuttgart, Germany	Collective mode in multicomponent superconductors: the case of FeSe
P-18	**Neumann**, Iuliia University of Stuttgart, Germany	Electrochemical modification and superconducting properties of tungsten bronzes
P-19	**Panda**, Siddhant University of Florida, USA	"Universal" Δ_{max}/T_c in Fe Based Superconductors
P-20	**Parshukov**, Kirill MPI for Solid State Research, Stuttgart, Germany	Interplay of superconductivity and altermagnetism: A symmetry perspective
P-21	**Rabinovich**, Ksenia MPI for Solid State Research, Stuttgart, Germany	Electronic, magnetic and structural instabilities of $Ca_3(Ru_{0.99}Ti_{0.01})_2O_7$
P-22	**Ravi Sankar**, Sushma Lakshmi MPI for Chemical Physics of Solids, Dresden, Germany	Effect of La-doping on the heavy-fermion superconductor $CeRh_2As_2$
P-23	**Rodehutskors**, Sophie MPI for the Structure and Dynamics of Matter, Hamburg, Germany	Focused Ion Beam Microstructuring of $BaFe_2(As_{(1-x)}P_{(x)})_2$
P-24	**Scholle**, Robin MPI for Solid State Research, Stuttgart, Germany	The zoo of states in the 2D Hubbard Model
P-25	**Suen**, Cissy MPI for Solid State Research, Stuttgart, Germany & UBC Vancouver, Canada	Electronic response of a Mott insulator at a current-induced insulator-to-metal transition
P-26	**Wiedmann**, Raymond MPI for Solid State Research, Stuttgart, Germany	Quantum geometry and optical properties of nodal planes
P-27	**Zhang**, Dongxin Laboratoire Albert Fert,Palaiseau, France	Synthesis of superconducting infinite-layer nickelate thin films by aluminum sputtering deposition
P-28	**Zhang**, Ling MPI for the Structure and Dynamics of Matter, Hamburg, Germany	Intrinsic pinning unveils layered modulation of superfluid density in high-field superconductivity of UTe_2
P-29	**Zimmermann**, Valentin MPI for Solid State Research, Stuttgart, Germany	Evolution of spin-orbital excitations from 4d to 5d TMOs

Introduction to Superconductivity

Manfred Sigrist

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Superconductivity, an extraordinary property exhibited by certain metals at low temperatures, was discovered by accident rather than predicted by theory. However, it has since become one of the most thoroughly understood and well-characterized phenomena in condensed matter physics. This lecture will cover the fundamental principles underlying the standard theory of superconductivity, progressing from the London and Ginzburg-Landau theories, which describe phenomenological aspects, to the BCS theory. The latter introduces the concept of coherent states of Cooper pairs, providing a comprehensive microscopic understanding of the phenomenon.

Today, the BCS framework is widely accepted as the cornerstone of our understanding of all known superconductors. However, the discovery of "exotic" superconductors about forty years ago revealed materials that do not conform to the usual BCS picture, prompting a distinction between *"conventional"* and *"unconventional"* superconductors. Conventional superconductors exhibit onsite electron pairing mediated by electron-phonon interactions. In contrast, unconventional superconductors avoid this type of pairing and instead rely on purely electronic interactions. This fundamental difference can give rise to unique features of symmetry-breaking in the superconducting phase, shaping the distinctive properties of unconventional superconductors.

The classification of the symmetry of Cooper pairs is based on two key symmetries: time-reversal symmetry and inversion symmetry. These allow as to separate Cooper pairing into the even-parity spin-singlet or odd-parity spin-triplet category. Additional characteristic features arises from the crystal lattice symmetries intrinsic to the superconducting material.

This lecture will highlight some of the defining physical signatures of unconventional superconductors, focusing in particular on the spontaneous symmetry-breaking phenomena unconventional Cooper pairing can induce. This framework will allow us to explore some distinctive physical features that signal unconventional superconductivity.

Theory of Unconventional Superconductivity: Cuprates and Nickelates

Thomas Schäfer

Max Planck Institute for Solid State Research (MPI-FKF), Stuttgart

Undoubtedly, the discovery of superconductivity in copper-oxide ceramics in 1986 by Georg Bednorz and Karl Alexander Müller has triggered an avalanche of experimental and theoretical research. On the one hand, this scientific excitement is rooted in the practical consequences of the potential realization of materials, which lose their electrical resistivity at ambient conditions - on the other hand, the exact mechanism of *how* the superconducting state in these materials is emerging is still not understood and poses a great challenge to quantum many-body theory.

In this lecture, I will give an introduction on the theory of unconventional superconductivity, contrast it to the (conventional) BCS framework, and present selected highlights of the contemporary computational modelization of superconductivity in cuprates and nickelates.

Superconductivity due to and in spite of magnetism

Mathias S. Scheurer

University of Stuttgart, Stuttgart, Germany

In this lecture, we will explore the ambivalent relation between superconductivity and magnetism. On the one hand, there are systems, such as the cuprate high-temperature superconductors, where fluctuations of antiferromagnetism are widely believed to be the key driving force behind the superconducting state. This is conveniently described by the spin-fermion model, which I will introduce and discuss in detail. On the other hand, it is known that the coexistence of superconductivity and long-range magnetic order is rather exotic. The reason is that the breaking of time-reversal symmetry associated with magnetic order can lift the degeneracy of Kramers' partners and, thus, removes the "Cooper log" rendering superconductivity a finite-coupling instability. If, nonetheless, superconductivity and magnetism do manage to coexist, this gives rise to a very rich phenomenology, which I will discuss. Finally, if time permits, I will also show how a superconductor can be manipulated to spontaneously become magnetic by itself.

Materials and mechanisms of superconductivity – How many roads to high-T_c?

Hidenori Takagi

Max Planck Institute for Solid State Research (MPI-FKF), Stuttgart

& Department of Physics, The University of Tokyo, Tokyo

In this lecture, I will discuss the materials route to high-T_c (and often exotic) superconductivity and the putative mechanisms behind them. To do so, a brief overview will be given on superconducting materials with a relatively high transition temperature T_c, including hydrides, layered cuprates, nickelates, iron pnictides, strongly covalent materials, molecular solids and interfaces.

Bipolaronic high-temperature superconductivity

Mona Berciu

SBQMI, UBC, Vancouver, Canada

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I will begin by reviewing the origins of the two types of electron-phonon couplings, and explain why they lead to polarons and bipolarons with very different properties. The first class of couplings, called g(q) models, always results in polarons and bipolarons whose effective mass increases very fast with the coupling strength, making high-temperature superconductivity impossible in such models. However, the second class of couplings, called g(k,q) models, can produce very light polarons and bipolarons even at very strong couplings [1],[2]. This re-opens the discussion on whether phonon-mediated high-temperature superconductivity might be possible. I will review recent results that argue that this could, indeed, be the case [3],[4].

References:

[1] D. Marchand et al., PRL 105, 266605 (2010)
[2] J. Sous, M. Chakraborty, R. V. Krems and M. Berciu, PRL 121, 248001 (2018)
[3] C. Zhang et al., PRX 13, 011010 (2023)
[4] J. Sous et al., PRB 108, L220502 (2023)

Computational Discovery of Conventional Superconductors

Eva Zurek

Department of Chemistry, University at Buffalo, State University of New York

Algorithms for crystal structure prediction, high-throughput calculations and *ab initio* techniques for obtaining the electron-phonon-coupling have opened the door for the computational prediction of conventional superconductors. In this talk, we provide an overview of these methods and describe how they are being employed to predict hydrogen-based supeconductors with record breaking critical temperatures that are stable at high pressures [1]. We also discuss efforts to predict conventional superconducting materials stable at atmospheric pressures such as borocarbide sodalite-like clathrates [2]. Finally, electronic structure analysis is employed to show why the critical temperature of predicted Mg_2IrH_6 is calculated to rival that of the cuprates, while replacing Mg for Ca in this same structure type kills its superconductivity [3]. Design principles for maximizing the superconducting critical temperature are discussed.

References:

[1] K. Hilleke, E. Zurek, J. Appl. Phys., 131, 070901 (2022).
[2] N. Geng, K. P. Hilleke, L. Zhu, X. Wang, T. A. Strobel, J. Am. Chem. Soc., 145, 1696 (2023).
[3] X. Wang, W. Pickett, M. Hutcheon, R. Prasankumar, arXiv:2407.10889 (2024)

An experimental view on superconductivity in the superhydrides

Audrey Grockowiak

Leibniz Institute, Dresden

The search for room temperature superconductivity has accelerated dramatically in the last few years, driven largely by theoretical predictions that first indicated alloying dense hydrogen with other elements could produce conventional phonon-mediated superconductivity at very high temperatures and at accessible pressures. More recently, the success of structure search methods have identified specific candidates and pressure-temperature (P-T) conditions for synthesis. These theoretical advances have prompted in turn improvements in experimental techniques to test these predictions. As a result, experimental studies of simple binary hydrides under pressure have yielded high critical superconducting transition temperatures (T_c), of 260 K in LaH_{10}, close to the commonly accepted threshold for room temperature, 293 K, at pressures near 180 GPa.

In this talk, I will discuss our recent efforts on the synthesis and characterization of a Lanthanum-based, higher order superhydride [1]. I will emphasize in particular the experimental methods developed to reach the most extreme conditions required to achieve the synthesis of this new family of superconductors.

References:

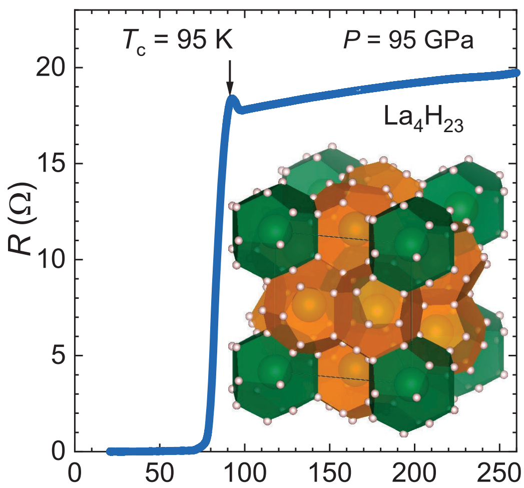
[1] Grockowiak, A. D. et al., Front. Electron. Mater, Volume 2 - 2022 2022
[2] Helm, T. et al., *Nat Commun* **11**, 3482 (2020).

Electronic and Structural Reconstructions in high-pressure superconductors

Sven Friedemann

HH Wills Physics Laboratory, University of Bristol, UK

Superconductivity is not restricted to low temperatures as has been demonstrated by the discovery of transition temperatures up to 260 K in LaH_{10}. This raises the prospect of superconductivity at even higher transition temperatures. However, experimental studies of superconductivity in hydrides remain an enormous challenge due to the large pressure scales required. I will present our independent confirmation of superconductivity in H_3S [1] where we identify clean-limit superconductivity and demonstrate the effects of thermal fluctuations. In addition, I present our discovery of the new superconductor La_4H_{23} and discuss structural instabilities [2]. I will discuss our experimental approach to Mbar experiments [3].



References:

[1] Osmond, I. et al. Phys. Rev. B (2022).
[2] Cross, S. et al. Phys. Rev. B 109, L020503 (2024).
[3] Buhot, J. *et al. Phys. Rev. B* **102**, 104508 (2020).

Unique selling points of (high-temperature) superconducting magnets and novel trends.

Prof. Dr. Tabea Arndt

Karlsruhe Institute of Technology, ITEP, Karlsruhe

Superconducting magnets offer special features, which can't be realized with normal conducting magnets or permanent magnets.

The physical background of these benefits is highlighted and the extended opportunities by High-Temperature Superconductors (HTS) are indicated. Furthermore, HTS offer not only an operation at elevated temperatures, but at very high fields, too; this gives use cases for new applications (NMR, MRI, separation, MagLev, rotating machines, accelerators, …) while at the same time simplifying the cooling technology.

The winding technology based on anisotropic HTS tapes becomes more challenging (e.g. use of robotic winding labs) but offers novel coil architectures like non-insulated windings or DUDA's (Disk-Up-Down-Assemblies).

In the limited timeframe, this contribution tries to take you on a quick journey through these aspects, which might be deepened in the discussion afterwards.

Recent Advances in the Optical Control of Superconductivity

Daniele Nicoletti

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Tailored optical excitation in some high-T_C cuprates and organic superconductors has been shown to induce superconducting-like coherence at temperatures far above T_C, as evidenced by the terahertz-frequency optical properties in the nonequilibrium state [1-3]. In $YBa_2Cu_3O_{6+x}$ (YBCO), this phenomenon was initially attributed to the nonlinear excitation of certain lattice modes in the mid infrared and the creation of new crystal structures [4]. More recent work, however, has associated this response to a parametric excitation and amplification of Josephson plasma polaritons, which are overdamped above T_C but are made coherent by the phonon drive [5].

In this lecture, I will discuss the most recent advances in the optical control of superconductivity, with special focus on YBCO. First, I will show how progressively longer mid-infrared driving pulses allowed the transient response to be extended over longer time scales, thus overcoming some ambiguities in the low-frequency optical properties [6]. In addition, I will report on a recent study of the time-dependent magnetic field surrounding optically-driven YBCO, measured by Faraday rotation in a magneto-optic material placed in the vicinity of the sample [7]. For a constant applied magnetic field and under the same driving conditions that result in superconducting-like optical properties, a transient diamagnetic signal was observed. This response is comparable in size with the Meissner effect found in a type-II superconductor at equilibrium.

References:

[1] D. Fausti *et al.*, Science 331, 189-191 (2011)
[2] W. Hu *et al.*, Nat. Mater. 13, 705-711 (2014)
[3] M. Mitrano *et al.*, Nature 530, 461-464 (2016)
[4] R. Mankowsky *et al.*, Nature 516, 71-73 (2014)
[5] A. von Hoegen *et al.*, Phys. Rev. X 13, 031008 (2022)
[6] A. Ribak *et al.*, Phys. Rev. B 107, 104508 (2023)
[7] S. Fava *et al.*, Nature 632, 75-80 (2024)

Probing condensates' coherence by TR-ARPES

Andrea Damascelli

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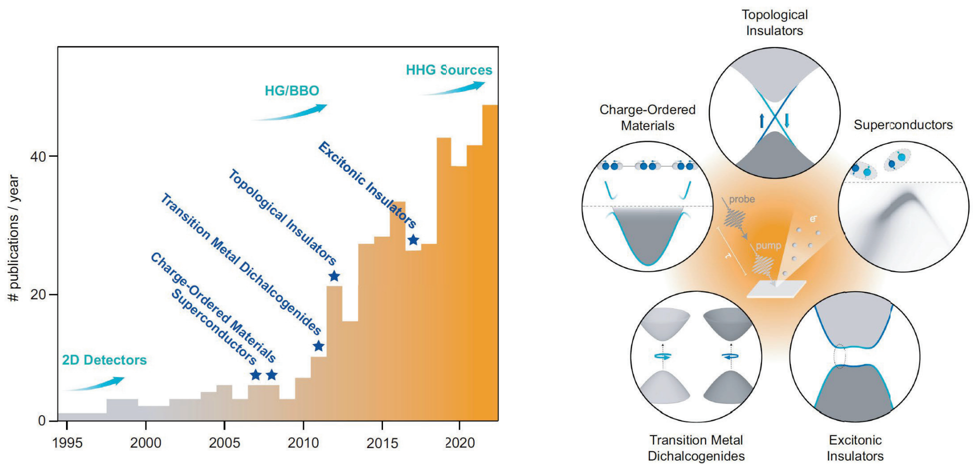
With its direct correspondence to the electronic structure, angle-resolved photoemission spectroscopy (ARPES) is a ubiquitous tool for the study of quantum materials. When extended to the temporal domain, time-resolved ARPES offers the potential to move beyond equilibrium properties, exploring both the unoccupied electronic structure as well as its dynamical response under ultrafast perturbation [1]. In this talk, I will discuss how ARPES – at equilibrium as well as in its time-resolved variance – can probe the coherence of many-body condensates, from high-temperature superconductivity [2,3] to spin-correlation-driven pseudogap [4].



References:

[1] F. Boschini, M. Zonno, A. Damascelli, Rev. Mod. Phys. **96**, 015003 (2024).
[2] F. Boschini *et al.*, Nature Materials **17**, 416 (2018).
[3] M. Zonno, F. Boschini, A. Damascelli, JESRP **251**, 147091 (2021).
[4] F. Boschini *et al.*, npj Quantum Materials **5**, 6 (2020).

When is a phase diagram not a phase diagram? Lessons learned from Sr_2RuO_4

Andy Mackenzie

Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

& University of St Andrews, Scotland

I will review recent developments in the experimental study of the thermodynamic properties of the superconducting state of one of the cleanest of all known unconventional superconductors, Sr_2RuO_4. After nearly two decades in which its superconducting state was thought to have a time-reversal symmetry breaking, odd parity order parameter of the form $p_x \pm ip_y$, recent NMR work has shown beyond reasonable doubt that its parity is in fact even. The focus of attention has now moved to whether or not it has a two-component order parameter and whether or not time reversal symmetry is broken.

Investigating these issues has raised a number of uncomfortable questions of a generality that goes beyond any physics specific to superconducting Sr_2RuO_4. One of the most common experimental activities in the fields of correlated electron physics and unconventional superconductivity is the construction of 'phase diagrams'. What is often being done in reality is taking some two-dimensional cut through a higher-dimensional phase space and plotting on it the positions of a series of experimentally observed anomalies. By referring to the results as 'phase diagrams', we make the implicit assumption that the boundaries of bulk thermodynamic phases have been identified. Based on our findings in strain-tuned Sr_2RuO_4, I will show that this implicit assumption should be treated with extreme caution, in relation not only to this particular material but likely to many others as well.

References:

[1] Grockowiak, A. D. et al., Front. Electron. Mater, Volume 2 - 2022
[2] Helm, T. et al., *Nat Commun* **11**, 3482 (2020).

Elastic tuning of unconventional superconductors

Hilary Noad

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Phase diagrams of unconventional superconductors often contain other states that are in close proximity to the superconductivity as a function of some tuning parameter such as doping, pressure, or magnetic field. From an experimental perspective, it is particularly desirable to have a tuning parameter that can be continuously changed during an experiment. With methods pioneered over the past decade that employ piezoelectric actuators to supply forces at low temperatures, elastic tuning, in which one manipulates a crystal by tensioning or compressing it, has become a powerful method for investigating unconventional superconductors [1]. In my lecture, I will describe how we can use stress and strain both to tune materials through large regions of their phase diagrams and to probe underlying symmetries.

References:

[1] Hicks *et al.*, Annu. Rev. Condens. Matter Phys. 16 (2025)

Topological Superconductors: From classification to recent examples

Andreas P. Schnyder

Max Planck Institute for Solid State Research (MPI-FKF), Stuttgart

In this lecture, I review the topological properties of unconventional superconductors. Starting from superconductors with a full pairing gap on the Fermi surface, the Kitaev superconductor, the chiral p-wave, and the helical p-wave superconductors are discussed. From these examples, the ten-fold classification of topological superconductors is derived. This is then further refined, by considering gapless superconductors, such as Dirac and Weyl superconductors, in two and three spatial dimensions, respectively. Furthermore, I will review some recent material examples, including UTe_2 and the Kagome superconductor AV_3Sb_5, where superconductivity is enhanced by van Hove singularities in the band structure.

Higgs spectroscopy in superconductors

Ryo Shimano

The University of Tokyo, Tokyo, Japan

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The study of collective modes is a fascinating issue as it provides deep insight into the properties of symmetry-broken ordered states in quantum materials. In superconductors, two collective modes are primarily expected to emerge associated with the spontaneous breaking of U(1) gauge symmetry: the phase mode and the amplitude mode. The later one, also termed as the Higgs mode, has long evaded the experimental observation because it does not couple to electromagnetic fields. The development of intense terahertz light source has changed this situation. Combined with nonlinear terahertz spectroscopy techniques [1,2,3], the observation of Higgs mode has been reported in a conventional s-wave superconductor NbN. Since then, intensive experimental and theoretical studies have been devoted to elucidate the microscopic mechanism of the light-Higgs couplings. Now, the nonlinear terahertz spectroscopy techniques are extended to unconventional superconductors including high-Tc cuprates [4,5] and iron-based superconductors [6,7], and also to superconductors under the supercurrent [8]. One captivating direction of this "Higgs spectroscopy" would be the application to further exotic superconductors exhibiting additional symmetry breakings. In this talk, I will overview the progresses on the study of Higgs mode in superconductors over the last decade. Recent developments on the study of Higgs modes and other collective modes in unconventional superconductors will be also introduced.

References:

[1] R. Matsunaga et al., Phys. Rev. Lett. **111**, 057002 (2013).
[2] R. Matsunaga et al., Science **345**, 1145 (2014).
[3] For a recent review, see R. Shimano and N. Tsuji, Ann. Rev. Cond. Mat. Phys. **11**, 103 (2020).
[4] K. Katsumi et al., Phys. Rev. Lett. **120**, 117001 (2018).
[5] H. Chu t al., Nat. Commun. **11**, 1793 (2020).
[6] K. Isoyama et al., Commun. Phys. **4**, 160 (2021).
[7] C. Vaswani et al., Nature Communications 12, 258 (2021).
[8] S. Nakamura et al., Phys. Rev. Lett. **122**, 257001 (2019).

Bus Shedule

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6	14 25 35 45 55
7	05 10 15 20 25 35 45 55
8	05 15 25 35 45 55
9	05 … 55
10	05 … 55
11	05 … 55
12	05 … 55
13	05 … 55
14	05 … 55
15	05 … 55
16	05 … 55
17	05 … 55
18	05 15 25 35 45 55
19	05 15 30 45 55
20	12 27 42 57
21	12 27 52
22	22 52

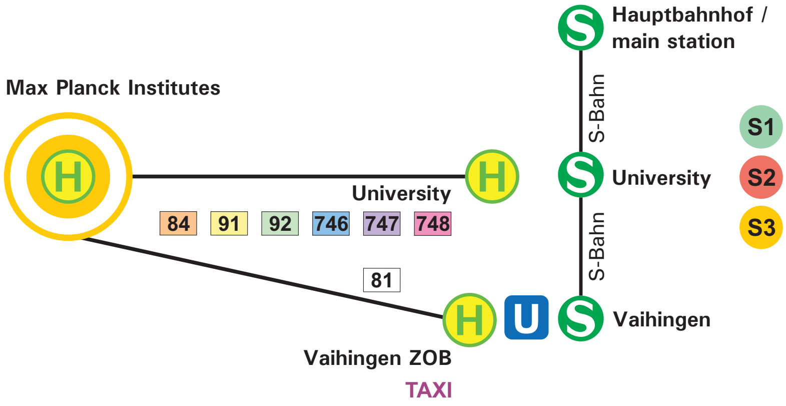
every 10 Min.

Vaihingen ZOB Linie 81

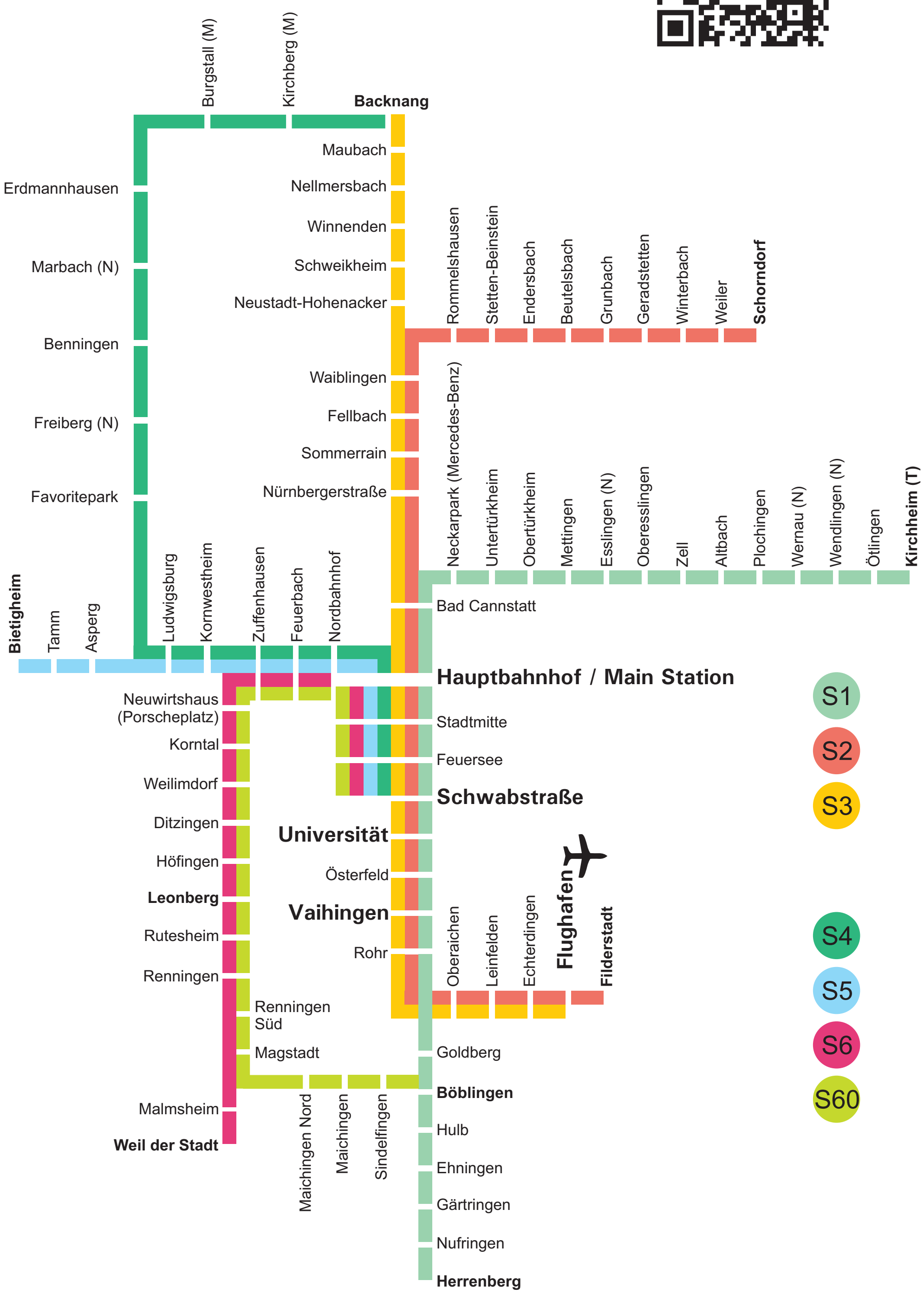
→ Max Planck Institutes

	Mon. – Fr.
4	38 53
5	08 23 38 53
6	08 24 39 49 59
7	09 19 29 39 49 59
8	09 … 59
9	09 … 59
10	09 … 59
11	09 … 59
12	09 … 59
13	09 … 59
14	09 … 59
15	09 … 59
16	09 … 59
17	09 … 59
18	09 19 29 39 49 59
19	09 19 29 39 52
20	07 22 37 52
21	07 24 52
22	23 53

every 10 Min.



S-Bahn Map



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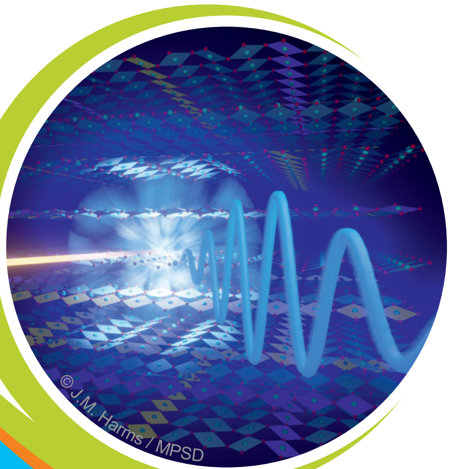

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