TT 39: Focus Session: Nickelate Superconductivity: Insights into Unconventional Pairing and Correlation Effects I (joint session TT/DS/MA)

Nickel, a direct neighbor of copper in the periodic table, has been considered a promising candidate for high-temperature superconductivity since the early 1990s. After more than three decades of research, this prediction was confirmed with the discovery of superconductivity in nickelates, marking the beginning of the "nickel age" of superconductivity. Recent advances include Sm-based infinite-layer nickelates with transition temperatures approaching 40 K, as well as bilayer nickelates exhibiting superconductivity above 90 K under pressure and up to 60 K under compressive epitaxial strain. These results highlight the crucial roles of structural engineering, epitaxial strain, and precise synthesis control, and they open new frontiers for both fundamental understanding and materials design. This focus session aims to define key scientific challenges ahead, strengthen collaboration within Germany and Europe, and accelerate progress toward higher superconducting transition temperatures.

Coordinators: Marta Gibert (TU Wien), Mattias Hepting (MPI FKF Stuttgart), Ilya M. Eremin (Ruhr-University Bochum)

Time: Wednesday 9:30–12:45 Location: HSZ/0003

Topical Talk TT 39.1 Wed 9:30 HSZ/0003

Unconventional Superconductivity in Infinite-layer Samarium Nickelates — •Danfeng Li — City University of Hong Kong, Kowloon, Hong Kong SAR, China

Infinite-layer nickelates have emerged as a frontier platform for studying unconventional superconductivity beyond the cuprates. In this talk, I will present our recent advances on samarium-based infinite-layer nickelate thin films, which exhibit enhanced superconductivity and a mixed two- and three-dimensional superconducting character arising from strong coupling between rare-earth $5d$ and Ni $3d$ orbitals. I will further highlight our discovery of robust field-induced re-entrant superconductivity in heavily Eu-doped $Sm_{0.95-x}Ca_{0.05}Eu_xNiO_2$, where superconductivity suppressed at low fields re-emerges above 6 T and persists to 45 T. This exotic high-field state results from the interplay between NiO-plane superconductivity and Eu^{2+}-sublattice ferromagnetism, revealing a unique coexistence of magnetism and superconductivity within a single material system. These findings demonstrate how rare-earth-site engineering and magnetic-field tuning provide powerful routes for realising and manipulating high-temperature ferromagnetic superconductivity.

[1] M. Yang, H. Wang, J. Tang, J. Luo et al., arXiv:2503.18346 (2025).
[2] M. Yang, J. Tang, X. Wu, H. Wang et al., arXiv:2508.14666 (2025).

Topical Talk TT 39.2 Wed 10:00 HSZ/0003

Recent insights into infinite-layer nickelate heterostructures from x-ray spectroscopy — •Eva Benckiser — Max Planck Institute for Solid State Research, Stuttgart, Germany

Nickelates have emerged as an important class of materials for studying unconventional superconductivity. However, the exact cation concentrations and oxygen stoichiometry in infinite-layer nickelates are difficult to determine due to the complex synthesis process. This has so far prevented the clear experimental identification of the nickel valence electron configuration in the superconducting phase.

In my talk, I will discuss our recent x-ray spectroscopy studies on $NdNiO_x$-$SrTiO_3$ heterostructures [1] and $PrNiO_x$ thin films [2] at various intermediate stages of topotactic reduction with $x = 2 - 3$. We find that even the most reduced films do not exhibit a pure Ni^{1+}-$3d^9$ configuration. The quantitative analysis shows that there is an average of 1.35 holes in the nickel $3d$ states and superconducting samples have even higher values [2]. These results challenge previous findings regarding the doping range in which superconductivity occurs in infinite-layer nickelates. Variations between samples are attributed to a complex interplay of ordered, self-doped regions, interfacial reconstructions, and disorder occurring on different length scales in both the cation and anion sublattices.

[1] R. A. Ortiz et al., Phys. Rev. Materials 9, 054801 (2025).
[2] R. Pons et al., submitted (2025).

Topical Talk TT 39.3 Wed 10:30 HSZ/0003

Theory of infinite-layer nickelate superconductors — •Karsten Held — TU Wien, Austria

The discovery of superconductivity in infinite-layer nickelates [1] marked a new age of superconductivity: the nickel age. Using density functional theory, dynamical mean-field theory and dynamical vertex approximation (DΓA [2]), we successfully predicted [3] the phase diagram T_c vs. Sr-doping of $Nd_{1-x}Sr_xNiO_2$ with –for an unconventional superconductor– unprecedented accuracy with defect free films synthesized only 3 years later [4]. Also, the normal state spin spectrum well agrees with resonant inelastic x-ray spectroscopy (RIXS) [5] and the one-particle spectrum with angular-resolved photoemission spectroscopy (ARPES) [6], which both enter into the calculation of T_c. With this excellent agreement to later experiments, we can now with some confidence calculate the phase diagram of finite-layer nickelates [7] and predict that infinite-layer nickelates have a much higher T_c under 100GPa of pressure even without any chemical doping [8].

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[1] D. Li et al., Nature 572, 624 (2019).
[2] G. Rohringer et al., Rev. Mod. Phys. 90, 25003 (2018).
[3] M. Kitatani et al., npj Quantum Materials 5, 59 (2020).
[4] K. Lee et al., Nature 619, 288 (2023).
[5] L. Si et al., Phys. Rev. Res. 6, 043104(2024).
[6] P. Worm et al., Phys. Rev. B 109, 235126 (2024).
[7] A. Hausoel et al., npj Quantum Mater. 10, 69 (2025).
[8] S. Di Cataldo et al., Nature Comm. 15, 3952 (2024).

15 min. break

Topical Talk TT 39.4 Wed 11:15 HSZ/0003

Disorder and distortions: what electrons tell us about nickelate superconductivity — •Berit H. Goodge — MPI-CPfS, Dresden, Germany

Recent realizations of superconductivity in both square-planar and bilayer Ruddlesden-Popper nickelates have opened a host of opportunities to explore fundamental questions of high-temperature superconductivity, while simultaneously posing unique synthetic challenges. Despite recent breakthroughs in sample synthesis, however, the highest quality thin films still pose immense challenges for investigation of fundamental characteristics, such as the pairing symmetry of the superconducting order parameter. Systematically introducing point-like disorder with high-energy electron irradiation consistently suppresses the superconducting transition, pointing towards a sign-changing order parameter in square-planar nickelates [1]. In parallel, epitaxial stabilization of superconductivity in bilayer nickelate thin films has opened the door to investigate local atomic structure and bonding environments. Leveraging the highest accessible spatial resolution and light-element sensitivity enabled by state-of-the-art multislice electron ptychography, we survey a series of bilayer nickelate thin films spanning a full series of tensile and compressive strain. We combine these experimental with strain-decomposed DFT calculations to investigate correlations between the observed atomic structure and superconductivity [2].

[1] Ranna et al., *PRL* 135, 126501 (2025).
[2] Bhatt et al., arXiv:2501.08204 (2025).

Topical Talk TT 39.5 Wed 11:45 HSZ/0003

Superconducting gap structure and bosonic mode in $La_2PrNi_2O_7$ thin films at ambient pressure — •Hai-Hu Wen — Hankou Rd. 22, Gulou, Nanjing, China

The recent discovery of high temperature superconductivity in nickelate systems has generated tremendous interests in the community. The core issue to understand the pairing mechanism is about the superconducting gap and its symmetry. We have successfully synthesized the superconducting thin films of $La_2PrNi_2O_7$ with $T_c\ ^{onset} = 41.5$ K, and measured the superconducting tunneling spectra after we expose the superconducting layer by using the tip-excavation technique. The spectrum shows a two-gap structure with $\Delta_1 = 9$ meV, $\Delta_2 =$ 6-8 meV, and fittings based on the Dynes model indicate that the dominant gap should have an s-wave structure with low anisotropy, this allows us to select the s^{+-}-pairing symmetry among the two possibilities s^{+-} and d-wave. Furthermore, a clear bosonic mode with energy $\Omega = 30 \pm 2$ meV is observed, which further supports a sign reversal gap[1]. Our results shed new light in understanding the mystery of superconductivity in bilayer nickelate superconductors.

Collaborators: Huan Yang, Ilya M. Eremin, Shengtai Fan, Mengjun Ou, Marius Scholten, Qing Li, Zhiyuan Shang, Yi Wang, Jiasen Xu

[1] S. Fan et al., arXiv: 2506.01788

TT 39.6 Wed 12:15 HSZ/0003

Investigation of Ruddlesden-Popper nickelates and the monolayer-trilayer polymorph using Raman spectroscopy —
•Vignesh Sundaramurthy[1], Abhi Suthar[1], Pascal Puphal[1,2], Hasan Yilmaz[3], Masahiko Isobe[1], Matteo Minola[1], Bernhard Keimer[1], and Matthias Hepting[1] — [1]Max-Planck-Institute for Solid State Research, Heisenbergstraße 1, 70569 Stuttgart, Germany — [2]2^{nd} Physics Institute, University of Stuttgart, 70569 Stuttgart, Germany — [3]University of Stuttgart, Institute for Materials Science, Materials Synthesis Group, Heisenbergstraße 3, 70569 Stuttgart, Germany

Ruddlesden-Popper nickelates have attracted intense interest following the discovery of superconductivity in several members of the series, including bilayer $La_3Ni_2O_7$, trilayer $La_4Ni_3O_{10}$, and structural polymorphs composed of monolayer-bilayer or monolayer-trilayer (ML-TL) units. In this talk, we explore the phononic and electronic Raman responses of high-quality ML-TL single crystals and contrast them with those of the other nickelate phases, using samples with optimized oxygen content.

TT 39.7 Wed 12:30 HSZ/0003

Multiorbital density wave in the trilayer nickelate $La_4Ni_3O_{10}$
— Abhi Suthar[1], Vignesh Sundaramurthy[1], Matias Bejas[2], Congcong Le[3], Pascal Puphal[1], Pablo Sosa-Lizama[1], Masahiko Isobe[1], Peter A. van Aken[1], Y. Eren Suyolcu[1], Matteo Minola[1], Andreas P. Schnyder[1], Xianxin Wu[4], Bernhard Keimer[1], Giniyat Khaliullin[1], Andres Greco[2], and •Matthias Hepting[1] — [1]Max-Planck-Institute for Solid State Research, Stuttgart, Germany — [2]UNR-CONICET, Rosario, Argentina — [3]RIKEN, Saitama, Japan — [4]Institute of Theoretical Physics, Beijing, China

Ruddlesden–Popper nickelates exhibit high-temperature superconductivity closely intertwined with charge and spin density wave order. However, fundamental questions persist regarding the orbital character and symmetry underlying the density wave instabilities. Using polarized Raman scattering on trilayer $La_4Ni_3O_{10}$, we resolve characteristic phonon anomalies and a redistribution of electronic spectral weight across the density wave transitions. Momentum-selective electronic Raman responses, combined with multiorbital model calculations, reveal a density-wave–induced gap with incoherent, non-mean-field opening and contributions from both Ni-$d_{x^2-y^2}$ and d_{z^2} states [1]. These results reconcile conflicting experimental reports of the density wave gap and underscore its multiorbital character.

[1] A. Suthar *et al.*, arXiv:2508.06440 (2025).