O 18: Poster Focus Session Ultrafast Electron Microscopy at the Space-Time Limit

Time: Monday 18:00–20:00 Location: P2

O 18.1 Mon 18:00 P2

Extending machine-learning-based band structure reconstruction into the time domain. — •Mirko Myksa[1], Rui Patrick Xian[1], Vincent Stimper[2], Martin Wolf[1], Ralph Ernstorfer[1], and Laurenz Rettig[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Max Planck Institute for Intelligent Systems, Tübingen, Germany

Reliably extracting the electronic band dispersion from angle-resolved experimental photoemission (ARPES) data poses a challenging task, which often relies on specific line shape models and underlying assumptions, and thereby limiting a systematic and large-scale band structure extraction from volumetric ARPES data. For such purposes, we recently developed a band-structure reconstruction pipeline, including probabilistic machine learning and the associated data processing [1]. This pipeline shows an excellent performance on benchmarks for the reconstruction of three-dimensional photoemission (kx, ky, E) data from various materials. Here, the prospect for extending such analysis towards further dimensions such as pump-probe delay time-resolved ARPES will be discussed.

[1] R.P. Xian, et al., Nat. Comput. Sci. 3, 101 (2023)

O 18.2 Mon 18:00 P2

Accessing energy- and momentum-dependent electron-phonon coupling from multidimensional photoemission data — •Hossein Yousofniadarzi, Julian Maklar, Martin Wolf, Ralph Ernstorfer, and Laurenz Rettig — Fritz Haber Institute of the Max Planck Society

Time- and angle-resolved photoemission spectroscopy (trARPES) provides a powerful method for probing ultrafast electron dynamics and their interactions with lattice vibrations. The electron-phonon (e-ph) interaction and its momentum dependence play an important role in many quantum materials, e.g., at the origin of charge-density-wave (CDW) formation. Here, we present an approach based on Fourier analysis, combined with a fitting procedure [1], that allows access to the energy and momentum dependence of the e-ph coupling strength for various coherent phonon modes in several CDW compounds. We discuss how these interactions vary across the Brillouin zone and contribute to the electronic structure modifications characteristic of the CDW phase. This work demonstrates the effectiveness of trARPES as a valuable technique for studying interactions in complex quantum materials.

[1] H. A. Hübener, et al., Phys. Rev. Lett. 125, 136401 (2020)

O 18.3 Mon 18:00 P2

Machine learning-based denoising and artefact removal for multidimensional photoemission data — •Joshka Laird, Tommaso Pincelli, and Laurenz Rettig — Fritz haber institute of the Max Planck Society, Berlin, Germany

Angle-Resolved Photoemission Spectroscopy (ARPES) is a powerful tool for investigating the electronic structure of materials. While modern approaches such as momentum microscopy provide rich, multidimensional photoemission data, they pose challenges for achieving high statistics data and good signal-to-noise ratios. Additionally, image distortions such as mesh artefacts often complicate the analysis. Traditional denoising techniques, while effective in specific scenarios, can fail to preserve the fine structural details essential for accurate interpretation.

Here, we present a machine learning-based denoising and artefact removal approach for multidimensional photoemission data. Based on recent results using convolutional neural networks [1], we discuss how to extend such networks to higher dimensions to cope with data e.g. from time-resolved momentum microscopy.

[1] Y. Kim et al., Rev. Sci. Instrum. 92, 073901 (2021)

O 18.4 Mon 18:00 P2

Towards the Investigation of Spin Systems With Electron Microscopy Tools — Antonín Jaroš[1,2], Johann Toyfl[1,2], Benjamin Czasch[1,2], •Michael Stanislaus Seifner[1,2], Isobel Claire Bicket[1,2], and Philipp Haslinger[1,2] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [2]University Service Centre for Transmission Electron Microscopy, TU Wien, Stadionallee 2, 1020 Wien, Austria

Electron spin resonance (ESR) spectroscopy is a method for studying unpaired electrons in various samples with applications in medicine, biology, chemistry, and physics. Typically, the spatial resolution of classical ESR is limited to a few micrometers preventing studying spin systems and their dynamics at the atomic level. To obtain a better understanding of such dynamics, this project aims to develop an ESR setup inside a transmission electron microscope by using the magnetic field created by the objective lens of the microscope to generate energetically separated spin states. A specially designed microcoil integrated into a standard specimen holder allows for exciting spin systems, and various approaches for measuring the resulting resonances are presented. Our results point out potential ways of investigating spin dynamics with sub-nanometer spatial resolution and high temporal resolution. The developed setup will enrich the field of electron microscopy by providing a non-invasive tool to investigate spin systems as well as certain electron beam-induced sample damage.

O 18.5 Mon 18:00 P2

Characterization and Improvement of the Electron Beam Stability and the Measurement Noise in Ultrafast Low-Energy Electron Microscopy — •Ole Böttger[1,2], Johannes Otto[1,2,3], Leon Brauns[1,2], and Claus Ropers[1,2,3] — [1]Department of Ultrafast Dynamics, Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Göttingen, Germany — [3]Max Planck School of Photonics

Ultrafast Low Energy Electron Microscopy (ULEEM) promises to uncover real-space dynamics on surfaces with few-picosecond temporal and nanometer spatial resolutions. Our group is currently developing such an instrument and has obtained first promising results [1]. The extended measurement durations required in this scheme require a high degree of long-term stability of the system. Here, we present results of energy, beam position and intensity stability measurements under various operating conditions, applied to both the laser pump and electron probe beam used. Moreover, we show results of state-of-the-art drift correction algorithms [2] applied to first ULEEM data [1].

[1] J. Otto et al., in preparation (2024).
[2] T. A. de Jong et al., Ultramicroscopy 213, 112913 (2020).

O 18.6 Mon 18:00 P2

Monochromatization of Electron Beams with Spatially and Temporally Modulated Optical Fields — •Neli Laštovičková Streshkova[1], Petr Koutenský[1], Tomáš Novotný[2], and Martin Kozák[1] — [1]Department of Chemical Physics and Optics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, CZ-121 16 Prague, Czech Republic — [2]Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, Prague CZ-12116, Czech Republic

Inelastic interaction between coherent light and free electrons is a powerful tool for modulating electron wave packets, typically resulting in periodic sidebands in the electron energy spectra. We present a novel approach leveraging a time-dependent frequency modulation of light fields to achieve spectral squeezing and monochromatization of free electron pulses. This method compensates for the energy chirp inherent to dispersive propagation in electron sources like TEMs and SEMs, where finite coherence lengths lead to broadened energy spectra. By correcting the chirped wave packet in the energy-time domain through inelastic interaction with tailored optical fields, we enable significant spectral narrowing. Up to 26% of the electron distribution is concentrated within a narrowed energy band, achieving spectral compression by a factor of five. This advancement has implications for high-resolution quantum sensing and electron-based spectroscopy, addressing a critical need for low-loss electron monochromatization.

O 18.7 Mon 18:00 P2

Spatio-Temporal Electron Propagation Dynamics in Au/Fe/MgO(001) in Nonequilibrium — Markus Heckschen[1], Yasin Beyazit[1], Elaheh Shomali[1], Florian Denizer[1], J. Jayabalan[1], Ping Zhou[1], Detlef Diesing[2], Markus Gruner[1], Rossitza Pentcheva[1], Axel Lorke[1], Björn Sothmann[1], and •Uwe Bovensiepen[1] — [1]University of Duisburg-Essen, Faculty of Physics and CENIDE, 47048 Duisburg — [2]University of Duisburg-Essen, Faculty of Chemistry, 45141 Essen

Since the mean free path of hot electrons is only a few nanometer, insights into the spatio-temporal electron dynamics are desired for the analysis of ultrafast microscopy. We determine the energy-dependent electron propagation time through epitaxial Au/Fe(001) as a function of Au layer thickness [1] by femtosecond time-resolved two-photon photoemission spectroscopy at energies 0.5-2.0 eV above E_F. By combining real-time time-dependent density functional theory and microscopic electron transport simulations we identify ballistic transport of minority electrons of the optically excited electron population. At lower energy, superdiffusive transport with 1-4 scattering events dominates. The effective electron velocity accelerates from 0.3 to 1 nm/fs with an increase in the Au layer thickness from 10 to 100 nm which is explained by electron transport that becomes preferentially aligned with the interface normal for thicker Au layers. On this basis the electron momentum or energy can be selected by the choice of the propagation layer thickness. We acknowledge funding by the DFG through SFB 1242. [1] Heckschen et al., PRX ENERGY **2**, 043009 (2023).