SYFC 1: Designing Quantum Materials With Light: from Floquet to Cavity Engineering

Time: Monday 9:30–12:15 Location: HSZ/AUDI

Invited Talk SYFC 1.1 Mon 9:30 HSZ/AUDI
Subcycle videography of strong-field controlled band structures — •Rupert Huber[1], Manuel Meierhofer[1], and Ulrich Höfer[1,2] — [1]Department of Physics and Regensburg Center for Ultrafast Nanoscopy (RUN), University of Regensburg, Germany — [2]Department of Physics, Marburg University, Germany

In lightwave electronics, the oscillating carrier field of intense light pulses has been utilized as an alternating bias to coherently accelerate electrons through solids [1]. Lightwave-driven closed quantum trajectories can lead to new eigenstates and tailored Floquet-Bloch band structures. We will first report how all-optical measurements can uniquely identify the presence of Floquet-Bloch states using high-order sideband generation [2]. A direct momentum-resolved observation of the formation and decay of Floquet-Bloch band structures on subcycle time scales has become available with ARPES-based band-structure videography [3]. While our lead-off experiments were limited to subcycle dynamics at small electron momenta, a novel approach using momentum microscopy with few-fs XUV pulses affords a panoramic view of strong-field dynamics throughout the first Brillouin zone. We will illustrate how this approach allows us to reveal the anatomy of strong-field light-matter interaction in quantum materials ranging from graphene to novel flat-band materials.

[1] Borsch et al., Nature Reviews Materials 8, 668 (2023); Kira et al., Optics and Photonics News 36, 28 (2025). [2] Freudenstein et al., Nature 610, 290 (2022); Kneller et al., in preparation. [3] Ito et al., Nature 616, 696 (2023); Reimann et al., Nature 562, 396 (2018).

Invited Talk SYFC 1.2 Mon 10:00 HSZ/AUDI
Engineering Quantum Materials through Structured Cavity Vacuum Fluctuations — •Angel Rubio — Max Planck Instittue for the Structure and Dynamics of Matter

Structuring the photon density of states in optical cavities enables control of material properties through strong light*matter coupling. Quantum Electrodynamical Density Functional Theory (QEDFT) extends TDDFT by incorporating quantized electromagnetic fields into electronic structure theory, providing an ab initio framework for predicting cavity-induced phenomena. Experiments such as photon-mediated superconductivity and optically engineered topological phases show that vacuum fluctuations, rather than classical light, can reshape material ground states and drive new quantum phases.

We present an ab initio approach to study cavity effects in two-dimensional materials. Using QEDFT, we show how vacuum fields modify van der Waals systems, inducing charge localization, tunable band gaps, and interlayer spacing that alter ferroelectric and optical responses. A non-perturbative Hartree*Fock framework further reveals cavity-mediated electron interactions in graphene and dichalcogenides, where anisotropic photon modes open Dirac gaps while isotropic ones renormalize the Fermi velocity. Cavity photons thus emerge as a new control parameter for correlated quantum states.

Invited Talk SYFC 1.3 Mon 10:30 HSZ/AUDI
Floquet engineering of quantum materials: from semiconductors to semimetals — •Shuyun Zhou — Department of Physics, Tsinghua University

Time-periodic light-field can dress the electronic states of quantum materials, providing a fascinating controlling knob for transient modifications of the electronic structure with versatile light-induced emergent phenomena. In this talk, I will present our recent experimental progress on the Floquet engineering of quantum materials using time- and angle-resolved photoemission spectroscopy (TrARPES). In particular, experimental progress on the Floquet engineering of semiconductors and semimetals. Experimental insights on Floquet engineering and light-matter interactions in quantum materials will also be discussed.

15 min. break

Invited Talk SYFC 1.4 Mon 11:15 HSZ/AUDI
(Quantum) Light Control of Materials — •Dante Kennes — RWTH Aachen University, Germany — MPSD Hamburg, Germany

Light offers a versatile handle for tailoring quantum materials. I will outline two complementary examples focusing on their theoretical and computational nonequilibrium quantum many-body descriptions: (i) Ultrafast optical drives can transiently reshape a solid's symmetry and electronic structure, where for the latter Floquet engineering provides the framework for accessing and stabilizing novel non-equilibrium phases [1]. (ii) Embedding a material in an optical cavity couples it to quantized photon modes, unlocking new many-body phenomena in the realm of cavity quantum electrodynamics [2]. I will close with an outlook on merging these strategies with the flexibility of two-dimensional heterostructures to enable on-demand design of quantum functionalities [3].

[1] Rev. Mod. Phys. 93, 041002 (2021)
[2] Appl. Phys. Rev. 9, 011312 (2022)
[3] Nat. Phys. 17, 155 (2021)

Invited Talk SYFC 1.5 Mon 11:45 HSZ/AUDI
Lightwave-driven electrons in a Floquet topological insulator — Daniel Lesko[1,2], Tobias Weitz[1,2], Weizhe Li[1], Selina Nöcker[1,2], Celina Hüttner[1], Tamara Pröbster[1], Simon Wittigschlager[1], Christian Heide[1,3], Ofer Neufeld[4], and •Peter Hommelhoff[1,2] — [1]Department Physik, Friedrich-Alexander-Universität, Erlangen — [2]Fakultät für Physik, Ludwig-Maxilians-Universität, München — [3]University of Central Florida, Orlando, Fl, USA — [4]Technion, Haifa, Israel

Topological insulators enable novel quantum and electronic phenomena but are limited by material constraints. Floquet topological insulators (FTIs), created by time-periodic driving, promise tunable topological properties and petahertz operation. We demonstrate optical control of photocurrents in light-dressed graphene, where circularly polarized pulses induce an FTI state and phase-locked second-harmonic pulses drive electron dynamics. This enables measurement of all-optical anomalous Hall and valley-polarized photocurrents, revealing sub-cycle phase sensitivity and dynamical symmetry selection rules. Supported by ab-initio and analytical theory, our results establish a bridge between Floquet and topological physics, attosecond science, and valleytronics, advancing ultrafast topotronic control beyond static band engineering.