TT 35: Focus Session: Correlations in Moiré Quantum Matter I

Topological quantum phenomena and breakthroughs in time-resolved spectroscopy pose new challenges for many-body theory: Spatio-temporal electronic correlations often strongly impact topological and dynamical material properties but at the same time hinder an unambiguous interpretation of experiments, let alone a reliable quantitative prediction of material properties. Moiré quantum matter, i.e. systems where fundamental electronic properties and correlation phenomena emerge beyond the atomic scale exemplify these challenges. This Focus Session brings together the most recent developments in the field.

Organizers: Roser Valentí (Goethe-Universität Frankfurt) and Tim Wehling (Universität Hamburg)

Time: Wednesday 15:00–18:15 Location: HSZ 03

Invited Talk TT 35.1 Wed 15:00 HSZ 03

Strongly correlated excitons in atomic double layers — •Phuong Nguyen[1], Liguo Ma[1], Raghav Chaturvedi[1], Kenji Watanabe[2], Takashi Taniguchi[2], Kin Fai Mak[1,3,4], and Jie Shan[1,3,4] — [1]School of Applied and Engineering Physics, Cornell University, Ithaca, NY, USA — [2]National Institute for Materials Science, Tsukuba, Japan — [3]Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, NY, USA — [4]Kavli Institute at Cornell for Nanoscale Science, Ithaca, NY, USA

Excitons (bound electron-hole pairs) in solids have been proposed as a platform to achieve high temperature Bose-Einstein condensation. The small exciton binding energy in conventional semiconductors has limited the condensation temperature to about 1 K. In the past several years, a new class of two-dimensional semiconductors with much larger exciton binding energy has emerged. In this talk, we discuss the development of transition metal dichacogenide double layer structures and electrical injection of interlayer excitons up to 10^{12} cm^{-2}. We establish electrical control of the chemical potential of interlayer excitons and probe their thermodynamic properties by capacitance measurements. We present experimental evidence for an excitonic insulating state and discuss the possibility of probing exciton superfluidity in the atomic double layer system.

Invited Talk TT 35.2 Wed 15:30 HSZ 03

The Quantum Twisting Microscope — •Shahal Ilani — Weizmann Institute

In this talk I will present a fundamentally new type of scanning probe microscope, the Quantum Twisting Microscope (QTM), capable of performing local quantum interference measurements at a twistable interface between two quantum materials. Its working principle is based on a unique tip, made of an atomically-thin two-dimensional material. This tip allows electrons to coherently tunnel into a sample at many locations at once, with quantum interference between these tunneling events, making it a scanning electronic interferometer. With an extra twist degree of freedom, our microscope becomes a momentum-resolving local probe, providing powerful new ways to study the energy dispersions of interacting electrons. I will present various experiments performed with this microscope, demonstrating quantum interference at room temperature, probing the conductance of in-situ twisting interfaces, and imaging local energy dispersions in a variety of quantum materials.

Invited Talk TT 35.3 Wed 16:00 HSZ 03

Light-driven phenomena in two-dimensional and correlated quantum materials — •Angel Rubio — Max Planck Institute for the Structure and Dynamics of Matter, Luruper Chaussee 149, 22761 Hamburg, Germany — Center for Computational Quantum Physics Flatiron Institute, Simons Foundation, 10010 NY, USA

We will introduce our newly developed quantum electrodynamics density-functional formalism (QEDFT) as a first principles framework to predict, characterize and control the appearance of ordered phases of strongly interacting light-matter hybrid. We will pursue whether it is possible to create these new states of materials as ground-states of the system. To this end we will show how the emerging (vacuum) dressed states resembles Floquet states in driven systems. Strong light*matter coupling in cavities provides a pathway to break fundamental materials symmetries, like time-reversal symmetry in chiral cavities. We will discuss how to realize non-equilibrium states of matter that have so far been only accessible in ultrafast and ultrastrong laser-driven materials. We illustrate the realization of those ideas in molecules and 2D materials and show that the combination of cavity-QED and 2D twisted vdW heterostructures provides a novel and unique platform for the seamless realization of a plethora of interacting quantum phenomena, including exotic and elusive correlated and topological phases of matter.

15 min. break

Invited Talk TT 35.4 Wed 16:45 HSZ 03

Cascade of transitions in twisted and non-twisted graphene layers within the van Hove scenario — •Laura Classen[1], Dmitry Chichinadze[2], Yuxuan Wang[3], and Andrey Chubukov[2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]University of Minnesota, Minneapolis, USA — [3]University of Florida, Gainesville, USA

Fermions in layered graphene structures are described by both spin and valley degrees of freedom. Due to weak coupling between valleys, this can lead to an approximate SU(4) symmetry made from combined spin and valley transformations, which plays out differently depending on filling and interactions. Motivated by measurements of compressibility and STM spectra in twisted bilayer graphene, we analyze the pattern of symmetry breaking for itinerant fermions near a van Hove singularity. Making use of the approximate SU(4) symmetry of the Landau functional, we show that the structure of the order parameter changes with increasing filling via a cascade of transitions. We compute the feedback from different spin/valley orders on fermions and argue that each order splits the initially 4-fold degenerate van Hove peak in a particular fashion, consistent with the STM data and compressibility measurements, providing a unified interpretation of the cascade of transitions in twisted bilayer graphene. Our results follow from a generic analysis of an SU(4)-symmetric Landau functional and are valid beyond a specific underlying fermionic model. We argue that an analogous van Hove scenario explains the cascade of phase transitions in non-twisted Bernal bilayer and rhombohedral trilayer graphene.

Invited Talk TT 35.5 Wed 17:15 HSZ 03

Topology and strong correlation: From twisted bilayer graphene to the boundary zeros of Mott insulators — •Giorgio Sangiovanni[1], Niklas Wagner[1], Gautam Rai[2], Lorenzo Crippa[1], Tim Wehling[2], and Roser Valentí[3] — [1]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg — [2]I. Institut für Theoretische Physik, Universität Hamburg — [3]Institut für Theoretische Physik, Goethe-Universität Frankfurt am Main

Strong electronic correlations drive materials towards atomic-like Mott phases. How to topologically classify these many-body insulators is an open and highly debated question. In this talk I am going to start from twisted bilayer graphene, an example of the interplay between low-energy protection of single-particle eigenvalues and non-perturbative effects of electron-electron interactions. From this, I plan to move to a broader concept which has been spelled out in rather different ways in the recent literature: topological Mott insulators. Most of the proposed realizations rely either on Hartree-Fock approximations or on appropriately defined auxiliary degrees of freedom. I am going to present a novel, remarkably simple way of describing a topological Mott insulator without long-range order, based on the topological properties of their Green's function zeros in momentum space. After discussing the fate of the bulk-boundary correspondence in these systems, I will show how the zeros can be seen as a form of "topological antimatter" with distinctive features associated to the annihilation with conventional topologically protected edge modes.

TT 35.6 Wed 17:45 HSZ 03

Transport and electron correlations in magic-angle twisted bilayer graphene: A dynamical mean field theory study — •Gautam Rai[1], Lorenzo Crippa[2], Giorgio Sangiovanni[2], Roser Valenti[3], and Tim Wehling[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Hamburg, Germany — [2]Institute for Theoretical Physics and Astrophysics, Julius-Maximilians-Universität Würzburg, Würzburg, Germany — [3]Institut für Theoretische Physik, Goethe-Universität Frankfurt am Main, Frankfurt am Main, Germany

Fully characterising the low-temperature phase diagram of magic-angle twisted bilayer graphene (MATBG) has proven to be one of the most compelling challenges in recent condensed matter physics. Correlation effects dominate due to the flatness of the low-energy bands. By varying doping and temperature, one can tune between superconductor, correlated-insulator, and strange metal phases. It has been difficult to apply standard strong-correlation computational techniques because of a topological obstruction, which precludes the existence of exponentially localized, symmetry-preserving Wannier functions for the flat bands. Recently, a heavy Fermion model has been proposed that successfully treats the hybrid localised-delocalised nature of MATBG [1]. We apply dynamical mean field theory (DMFT) to the heavy Fermion model to describe electron correlation effects in MATBG. In particular, we demonstrate how filling commensurability affects transport at low temperatures.
[1] Z. D. Song and B. A. Bernevig, PRL 129, 047601 (2022)

TT 35.7 Wed 18:00 HSZ 03

Moiré minibands of twisted MoS_2 heterostructures — •Chithra H. Sharma[1,2], Marta Prada[1], Jan-Hendrick Schmidt[1], Lars Tiemann[1], Tobias Stauber[3], Takashi Taniguchi[4], Kenji Watanabe[4], Robert Zierold[1], Kai Rossnagel[2], and Robert H. Blick[1,5] — [1]Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]CAU Kiel, Leibnitzstrasse 19, 24118 Kiel — [3]ICMM-CSIC, Sor Juana Inés de la Cruz 3, Madrid 28049 Spain — [4]Research Center for Functional Materials, National Institute for Materials Science, Namiki 1-1, Tsukuba, 305-0044, Ibaraki, Japan — [5]Material Science and Engineering, University of Wisconsin-Madison, University Ave. 1550, Madison, 53706, Wisconsin, USA

In the last decade, the evolution of van der Waals material systems has provided a multitude of options to manipulate, control, and engineer materials properties to various needs by combination, proximity, and twisting. Moiré superlattices formed as a result of lattice mismatch or twist angle modify the electronic structure to create flat bands and host exotic correlated electron phases. Here we observe the existence of low-dispersing mini-bands near the conduction band edge of MoS_2 twisted devices. We employ transport measurements and resolve discrete states within the band gap at low temperatures, in agreement with first-principles density functional theory calculations. We could also infer that the mini-bands correspond to iso-spin flavors as a result of interaction in the system coherent with our temperature dependence.