HL 32: Twisted Bilayer Graphene (jointly with DY, MA, HL, DS, O) (joint session TT/HL)

Time: Tuesday 14:00–15:45 Location: HSZ 201

HL 32.1 Tue 14:00 HSZ 201

Valley splitter and transverse valley focusing in twisted bilayer graphene — •Christophe De Beule[1], Peter Silvestrov[1], Ming-Hao Liu[2], and Patrik Recher[1,3] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan — [3]Laboratory for Emerging Nanometrology, 38106 Braunschweig, Germany

We study transport through electrostatic barriers in twisted bilayer graphene and show that for certain configurations, electrons from the K (K') valley are transmitted only to the top (bottom) layer, leading to valley-layer locked bulk currents. We show that such a valley splitter is obtained when the potential varies slowly on the Moiré scale and the Fermi energy in the barrier exceeds the kinematic barrier between Dirac electrons from the top and bottom layer. Furthermore, we show that for a given valley the current is transversely deflected, as time-reversal symmetry is broken in each valley separately, resulting in valley-selective transverse focusing at zero magnetic field.

HL 32.2 Tue 14:15 HSZ 201

Quantum capacitive coupling in large-angle twisted graphene layers — •Ming-Hao Liu — Department of Physics, National Cheng Kung University, Tainan, Taiwan

Magic-angle twisted bilayer graphene (tBLG) has revealed exotic physics of strong correlation in graphene systems and attracted enormous attention on twistronics of 2D materials. In the opposite extreme of large twist angles, relatively less attention has been paid. Due to the required large momentum change, scattering between different graphene layers of large-angle tBLG is forbidden. Through quantum capacitance of individual graphene layers, however, tBLG is electrostatically coupled, though electronically decoupled. Here, I introduce a self-consistent electrostatic model for carrier densities in decoupled tBLG systems and apply the model to perform quantum transport simulations for a recent experiment on a dual-gated large-angle tBLG device [1]. Good agreement between the experiment and theory confirms the electronic decoupling and indicates that the decoupled large-angle tBLG can be the thinnest parallel-plate capacitor in the world. The model can be further generalized to multi-layer systems composed of decoupled graphene sheets.

[1] P. Rickhaus *et al.*, arXiv:1907.00582 (2019).

HL 32.3 Tue 14:30 HSZ 201

Skyrmion lattices in twisted bilayer graphene — •Thomas Bömerich, Lukas Heinen, and Achim Rosch — Institute for Theoretical Physics, University of Cologne, Germany

We investigate the groundstate properties of magnetic skyrmions in anomalous Quantum Hall (AQH) systems. In these systems, the topological charge density, which characterizes the winding of a skyrmion, is directly proportional to the electric charge density. Therefore magnetic skyrmions are electrically charged excitations stabilized by Coulomb interactions between each other. At finite densities the skyrmions form regular lattices and can be controlled by external gate voltages. Our theory can be applied to twisted bilayer graphene as there is experimental evidence of ferromagnetic order and an AQH effect at specific fillings.

Starting from a free energy functional, we solve some limiting cases analytically and use micromagnetic simulations to study the lattice structure as a function of skyrmion density and skyrmion radius. From this we obtain a phase diagram with different skyrmion lattices. In particular we analyse the groundstate and its symmetries without external magnetic field. Additionally, we calculate the total magnetization as a function of skyrmion density, which can be used to detect experimental signatures of skyrmions in AQH systems.

HL 32.4 Tue 14:45 HSZ 201

Magnetism of magic-angle twisted bilayer graphene — •Javad Vahedi[1,2], Andreas Honecker[2], Robert Peters[3], and Guy Trambly de Laissardière[2] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, Germany — [2]Laboratoire de Physique Théorique et Modélisation, Université de Cergy-Pontoise, France — [3]Department of Physics, Kyoto University, Japan

Recently, correlated insulators and superconductivity have been discovered experimentally in twisted bilayer graphene (TBG) [1]. The Moiré pattern of the bilayers at so-called "magic angles" leads to localization of the low-energy electrons in the AA-stacking regions, reflected by very flat regions in the band structure [2]. This reduction of the kinetic energy enhances the relative importance of interactions and thus renders the bilayer systems much more susceptible to correlation effects than a single layer. We investigate the magnetic instabilities at half filling in TBG using a real-space Hartree-Fock and RPA analysis. We find that at charge neutrality an antiferromagnetic state localized in the AA region emerges for values of the Coulomb interaction U that are an order of magnitude smaller than what would be required to render an antiferromagnetic state in a single graphene sheet. Furthermore, doping of a few electrons per Moiré unit cell pushes the system into a ferromagnetic phase.

[1] Y. Cao *et al.*, Nature **556**, 80 (2018); Nature **556**, 43 (2018)
[2] G. Trambly de Laissardière *et al.*, Nano Letters **10**, 804 (2010)

HL 32.5 Tue 15:00 HSZ 201

Quantum diffusion in twisted bilayer graphene — •Guy Trambly de Laissardière[1], Omid Faizy Namarvar[2,3], Ahmed Missaoui[1], Javad Vahedi[1,4], Andreas Honecker[1], Laurence Magaud[2], and Didier Mayou[2] — [1]Laboratoire de Physique Théorique et Modélisation, CNRS (UMR 8089), Univ. de Cergy-Pontoise, France — [2]Institut Néel, CNRS, Univ. Grenoble Alpes, France — [3]XLIM, Univ. Limoges, CNRS (UMR 7252), Limoges, France — [4]Department of Physics and Earth Sciences, Jacobs University Bremen, Germany

It has been shown theoretically and experimentally that twisted bilayer graphenes (TBG), forming Moiré patterns, confine electrons in a tunable way as a function of the angle of rotation of one layer with respect to the other. Since 2018 the discovery of correlated insulators and superconductivity at so-called "magic angles" has stimulated an avalanche of experimental and theoretical activities. In the framework of the Kubo-Greenwood formula for the conductivity, we present tight-binding calculations of quantum diffusion properties in TBG at various angles including the first magic angle. We analyze in particular the effect of static defects, the effect of an electric bias and electron-electron interactions. One of the main results is the decisive role of inter-band transitions [1] in the conductivity of TBG at the magic angle.

[1] G. Trambly de Laissardière et al., Phys. Rev. B **93**, 235135 (2016).

HL 32.6 Tue 15:15 HSZ 201

Fractional quantum Hall states for Moiré superstructures in the Hofstadter regime — •Bartholomew Andrews and Alexey Soluyanov — Department of Physics, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

We apply a perpendicular magnetic field to the minimal effective two-orbital Fermi-Hubbard model based on a description of the low-energy physics of twisted bilayer graphene at the first magic angle. Through the use of a Peierl's substitution, we determine the Landau level splitting and study the structure of the resulting Chern bands for a range of magnetic flux per plaquette. We identify isolated, topological, and flat bands in the spectrum at low energies. We show that, with the inclusion of a nearest-neighbor density-density interaction, fractional quantum Hall states can be realized solely within these flat bands. Specifically, we characterize the $\nu = 1/3$ Laughlin state through the use of change pumping, spectral flow, entanglement scaling, and CFT edge state counting; and we analyze its dependence on orbital mixing. Ultimately, we comment on the applicability of this model for experiment.

HL 32.7 Tue 15:30 HSZ 201

Kernel Polynomial Method applied to Twisted Bilayer Graphene — Van-Nam Do[1], Duy Nguyen Van[1], Anh Le Hoang[1], and •Dario Bercioux[2,3] — [1]Phenikaa Institute for Advanced Study (PIAS), C1 Building, Phenikaa University, Hanoi 10000, Vietnam — [2]Donostia International Physics Center (DIPC), Paseo Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation of Science, 48011 Bilbao, Spain

We apply the Kernel Polynomial Method (KPM) [1] for investigating various spectral properties of twisted bilayer graphene. Contrary to standard methods based on Bloch's theorem, with the use of the KPM we can investigate twisted bilayer graphene with any twist angle, commensurate and incommensurate [2]. We show how within the KPM it is possible to study the evolution of a state, initially localized on one of the layers, to the other one. The resulting oscillating behaviour resembles Fabry-Pérot-like oscillations. We show that the characteristic transfer time between the two layers has a minimal dependence on the twist angle [3]. We further show how the chiral structure of twisted bilayer graphene allows for a finite transverse optical Hall conductivity even in the absence of external magnetic fields [4].

[1] Weiße *et al.*, Rev. Mod. Phys. **78**, 275 (2006).
[2] H. A. Le & V. N. Do, Phys. Rev. B **97**, 125136 (2018).
[3] H. Nam Do, H. Anh Le, & D. Bercioux, Phys. Rev. B **99**, 165127 (2019).
[4] V. Nam Do, H. Anh Le, V. Duy Nguyen, S. Ta Ho & D. Bercioux *in preparation.*