HL 24: Graphene and 2D Materials (joint session TT/HL)

Time: Wednesday 9:30–11:15 Location: H 3007

HL 24.1 Wed 9:30 H 3007

Static and Dynamic Properties of a 2D Superconductor Investigated by NV Center SPM — •Sreehari Jayaram, Malik Lenger, Ruoming Peng, Rainer Stöhr, and Jörg Wrachtrup — 3rd Physics Institute, University of Stuttgart, Germany

Visualization of nanoscale dynamics in superconducting materials provides a pathway to unravel the pairing mechanisms of interacting electrons. Here, we have employed the state-of-the-art scanning NV probe technique to explore the local magnetic response of the 2D superconductor, 2H-NbSe$_2$, in which we demonstrate full dynamic sensing of vortices with high sensitivity and spatial resolution.

Utilizing this quantum probe, we present the first spatio-temporal dynamics of vortices in a 10 nm thin exfoliated 2H-NbSe$_2$, where the arrangement of the vortices show a strong correlation with the geometric confinement. Notably, we have observed the melting of vortex solids near critical temperature allowing the re-arrangement of the vortices that is governed by the cooling rate.

Additionally, our study delves into the dynamics of vortex cores, superconducting-insulator edge dynamics, and phase transitions, all unveiled through spatial-temporal noise spectroscopy with the NV probe.

HL 24.2 Wed 9:45 H 3007

Berry Phase Effects in the Transverse Conductivity of Fermi Surfaces and its Detection With Spin Qubits and NMR — •Mark Morgenthaler and Inti Sodemann — Universität Leipzig, Germany

The transverse conductivity of clean Fermi liquids at low frequencies displays a remarkably universal behaviour at long wavelengths: It is determined only by the geometrical radius of curvature of the Fermi surface, and does not depend on details such as the quasi-particle mass or their interactions. Here, we demonstrate that the Berry phase at the Fermi surface does not alter such long-wavelength universality by directly computing the transverse conductivity of two- and three-dimensional electronic systems with Dirac dispersions, such as those appearing in 2D graphene or in 3D Dirac semi-metals and in the bulk of 3D topological insulators. Interestingly however, such universality ceases to hold at wave-vectors comparable to the Fermi radius, and Dirac fermions display a distinct transverse conductivity from a featureless parabolic Fermion. We demonstrate that this difference originates entirely from the orbital magnetic moment of the quasi-particles induced by their Berry phases. We discuss how these effects can be probed by measuring the T1 relaxation time of spin qubits (such as NV centers) near 2D samples and for the nuclear spins measured in NMR for 3D samples.

HL 24.3 Wed 10:00 H 3007

Fermi Velocity renormalization in graphene from large scale Quantum Monte Carlo simulations — •Maksim Ulybyshev[1], Savvas Zafeiropoulos[2], Christopher Winterowd[3], and Fakher Assaad[1,4] — [1]Julius-Maximilians-Universität Würzburg, Germany — [2]Aix Marseille Univ, Universite de Toulon, CNRS, CPT, Marseille, France — [3]Johann Wolfgang Goethe-Universität Frankfurt am Main, Germany — [4]Würzburg-Dresden Cluster of Excellence ct.qmat, Würzburg, Germany

Through recent advancements in algorithms, we extended the capabilities of unbiased Quantum Monte Carlo (QMC) simulations up to the lattices with spatial volume of 20808 sites. These simulations were applied to both suspended graphene and graphene on substrates, enabling direct comparison with experimental data without the need for additional extrapolations. This technique allowed us to successfully confront the numerical and experimental estimates of the Fermi velocity renormalization near the Dirac point.

Our findings validate the logarithmic divergence of the Fermi velocity, but also show the limitations of the low-energy continuum theory in quantitative description of this divergence. Additionally, our research demonstrates the significance of lattice-scale physics and higher-order perturbative corrections beyond the Random Phase Approximation (RPA) for a more accurate description of the experimental data for the Fermi velocity renormalization in suspended graphene. We also propose experimental approaches to demonstrate the role of higher-order perturbative corrections.

HL 24.4 Wed 10:15 H 3007

Solitons induced by an in-plane magnetic field in rhombohedral multilayer graphene — •Max Tymczyszyn, Peter Cross, and Edward McCann — Department of Physics, Lancaster University, Lancaster LA1 4YB, United Kingdom

The low-energy band structure of rhombohedral graphene multilayers includes a pair of flat bands near zero energy, which are localized on the surface layers of a finite thin film. Introducing an in-plane magnetic field we find that the zero-energy bands persist, and that level bifurcations occur at energies determined by the component of the in-plane wave vector that is parallel to the external field. The occurrence of level bifurcations is explained by invoking semiclassical quantization of the zero-field Fermi surface of rhombohedral graphite. We find parameter regions with a single isoenergetic contour of Berry phase zero corresponding to a conventional Landau level spectrum and regions with two isoenergetic contours, each of Berry phase π, corresponding to a Dirac-like spectrum of levels. We write down an analogous one-dimensional tight-binding model and relate the persistence of the zero-energy bands in large magnetic fields to a soliton texture supporting zero-energy states in the Su-Schrieffer-Heeger model. We show that different states contributing to the zero-energy flat bands in rhombohedral graphene multilayers in a large field are localized on different bulk layers of the system, not just the surfaces.

[1] M. Tymczyszyn, P.H. Cross, E. McCann, Phys. Rev. B 108 (2023) 115425

HL 24.5 Wed 10:30 H 3007

Competing nematic semi-metallic and insulating states in bilayer graphene — •Sebastian Mantilla and Inti Sodemann — Institut für Theoretische Physik, Universität Leipzig, 04107 Leipzig, Germany

The finite density of states arising from the parabolic band touching in ideal Bernal bilayer graphene leads to spontaneous symmetry-breaking instabilities driven by weak repulsive interactions. To this date, different experiments have reported conflicting states, with some reporting a gapped state and others a metallic state that spontaneously breaks lattice rotations. Using a combination of bosonization and self-consistent Hartree-Fock theory, we propose a resolution to these conflicting reports by demonstrating the existence of two closely competing states: a semi-metallic nematic state in which the parabolic band touchings spontaneously split into a pair of linearly dispersing Dirac fermions and a fully gapped state. We find that the gapped state has slightly lower energy, but the energy difference between them is highly sensitive to the interaction strength in a BCS-like fashion. Therefore, in samples with more screening, these states are even closer in energy, and their energetic balance can be tilted by other corrections, such as the trigonal warping, which tends to favour the nematic metallic states.

HL 24.6 Wed 10:45 H 3007

Atomistic approach to correlations in multilayer graphene — •Ammon Fischer[1], Lennart Klebl[2], Tim Wehling[2], and Dante M. Kennes[1,3] — [1]Institute for Theory of Statistical Physics, RWTH Aachen University — [2]I. Institute for Theoretical Physics, Universität Hamburg, Notkestraße 9-11, 22607 Hamburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany

Multilayer graphene has recently attracted considerable attention due to the discovery of cascades of correlated states and superconductivity driven by displacement field tunable van-Hove singularities at low densities. While experimental efforts aim to stabilize correlated phases by proximity-induced spin-orbit coupling or by increasing the number of graphene layers in the stack, first-principle guided theoretical investigations are thwarted by the strong momentum-localization of the low-energy degrees of freedom around the valleys K,K'. Here, we discuss how correlated phenomena in few-layer graphene can be resolved by atomistic weak-coupling methods including the random-phase approximation and the functional renormalization group using ab-initio derived interaction profiles. We demonstrate that the gap between phenomenological continuum model studies and atomistic investigations can be bridged by a novel Wannierization procedure that permits to relax the strong momentum-localization of the low-energy Bloch states. This enables a well-defined downloading procedure of long-ranged Coulomb interactions to the valley-local flat bands of multilayer graphene systems subject to external displacement fields.

HL 24.7 Wed 11:00 H 3007

Pseudomagnetotransport in strained and scaled graphene — Jia-Tong Shi, Aitor Garcia-Ruiz, and •Ming-Hao Liu — Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan

Graphene is highly susceptible to externally applied mechanical deformation due to its atomic thinness. As such, strained graphene has long been studied both theoretically and experimentally. Among all interesting predictions, the pseudo-magnetic field in graphene under properly designed strain fields, giving rise to effects equivalent to graphene under a strong external magnetic field on the order of 10 Tesla [1], is perhaps one of the most intensively discussed topics. Despite the experimentally observed pseudo-Landau levels due to strong pseudo-magnetic fields in graphene bubbles [2] and ripples [3], transport experiments showing strong pseudo-magnetic fields in strained graphene have so far been missing. To provide reliable guides to possible future pseudo-magnetotransport experiments on strained graphene, here we perform quantum transport simulations considering triaxially strained graphene using the scalable tight-binding model [4]. Numerical examples of transverse pseudo-magnetic focusing and pseudo-quantum Hall effect will be shown.

[1] F. Guinea, M. I. Katsnelson, A. K. Geim, Nat. Phys. **6** (2010) 30
[2] N. Levy *et al.*, Science **329** (2010) 544
[3] S. Y. Li *et al.*, Phys. Rev. Lett. **124** (2020) 106802
[4] M.-H. Liu, *et al.*, Phys. Rev. Lett. **114** (2015) 036601