High temperature pairing in a strongly interacting two-dimensional Fermi gas

Puneet A. Murthy[1], **Mathias Neidig**[1], **Ralf Klemt**[1], **Luca Bayha**[1], **Igor Boettcher**[2], **Tilman Enss**[3], **Marvin Holten**[1], **Gerhard Zürn**[1], **Philipp Preiss**[1] **and Selim Jochim**[1]

[1]*Physics Institute, Heidelberg University, Heidelberg, Germany*
[2]*Department of Physics, Simon Fraser University, Burnaby, BC, Canada*
[3]*Institute for Theoretical Physics, Heidelberg University, Heidelberg, Germany*

In this poster, I will present our recent experimental observations of many-body pairing in the normal state of a strongly interacting two-dimensional Fermi gas. We use spatially resolved radio-frequency spectroscopy to measure the spectral response of the system across the BEC-BCS crossover. On the BEC side, we find that the measured pairing energy agrees with the expected two-body binding energy. However, in the strongly interacting crossover regime, the pairing energy deviates significantly from the two-body expectation and more importantly exhibits a clear dependence on the local density. This indicates that the pairing phenomena in this regime is strongly modified by many-body effects. The fact that we observe this effect at temperatures as high as the Fermi temperature shows that the many-body pairing phenomenon is extremely robust against thermal fluctuations.

[1] P. A. Murthy et al., arXiv:1705.10577 (2017)

Condensates in double-well potential with synthetic gauge potentials and vortex seeding

Rukmani Bai[1], **Arko Roy** [1,2], **D. Angom** [1] **and P. Muruganandam**[3]

[1] *Physical Research Laboratory, Navrangpura, Ahmedabad-380009, Gujarat, India*
[2] *Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany*
[3] *School of Physics, Bharathidasan University, Tiruchirapalli 620 024, Tamil Nadu, India*

We demonstrate an enhancement in the vortex generation when artificial gauge potential is introduced to condensates confined in a double well potential. This is due to the lower energy required to create a vortex in the low condensate density region within the barrier. Furthermore, we study the transport of vortices between the two wells, and show that the traverse time for vortices is longer for the lower height of the well. We also show that the critical value of synthetic magnetic field to inject vortices into the bulk of the condensate is lower in the double-well potential compared to the harmonic confining potential.

Thermalisation of Bose-Einstein Condensates in Two-Dimensional Magnetic Potentials

Adam J. Barker, University of Oxford

Abstract

We have developed multiple radiofrequency (RF) dressed magnetic potentials for ultracold atoms, forming trap geometries such as a double well or a broad single well [1]. Reducing the amplitude of RF dressing fields can lead to two-dimensional (2D) confinement for trapped atoms [2] and tuning other system parameters can produce homogeneous 2D potentials. Our plan is to use a two-dimensional double well system in order to illuminate the route to thermal equilibrium of a non-integrable closed quantum system. It is expected that 2D quantum systems thermalise since their dynamics are sufficiently unconstrained, i.e. they are non-integrable [3]. The enhanced role of density fluctuations makes 2D systems very different, as predictions suggest they thermalise because of the creation of vortex-antivortex pairs, which alter phonon propagation [4]. Ultracold quantum gases are very well suited to observe thermalisation dynamics because they can be isolated from the environment and their dynamics can be spatially and temporally resolved. Our planned experiments will begin with a pair of 2D, degenerate Bose gases prepared in an non-equilibrium state via a sudden quench. We will investigate the relaxation of their relative local phase, through interferometric measurements and high-resolution images of the density as a function of time. In addition, our RF-dressed magnetic traps are inherently species-selective and could be extended to investigate the effect of impurities on relaxation in quantum systems [5].

References

[1] T. L. Harte, E. Bentine, K. Luksch, A. J. Barker, D. Trypogeorgos, B. Yuen, and C. J. Foot. Ultracold atoms in multiple-radiofrequency dressed adiabatic potentials. *arXiv:1706.01491*, 6 2017.

[2] K. Merloti, R. Dubessy, L. Longchambon, A Perrin, P-E Pottie, V. Lorent, and H. Perrin. A two-dimensional quantum gas in a magnetic trap. *New Journal of Physics*, 15(3):033007, 3 2013.

[3] L. Mathey and A. Polkovnikov. Light cone dynamics and reverse Kibble-Zurek mechanism in two-dimensional superfluids following a quantum quench. *Phys. Rev. A*, 81(3):1–13, 12 2009.

[4] L. Mathey, K. J. Günter, J. Dalibard, and A. Polkovnikov. Dynamic Kosterlitz-Thouless transition in two-dimensional Bose mixtures of ultracold atoms. *Phys. Rev. A*, 95(5):053630, 5 2017.

[5] E Bentine, T L Harte, K Luksch, A J Barker, J Mur-Petit, B Yuen, and C J Foot. Species-selective confinement of atoms dressed with multiple radiofrequencies. *J. Phys. B*, 50(9):094002, 5 2017.

Generation of many vortices through rotatory Dicke phase transition

Priyam Das[1],*, Mehmet Emre Tasgin[1], Ozgur E. Mustecaplioglu[2]

[1]Institute of Nuclear Physics, Hacettepe University, Ankara 06800, Turkey
[2]Department of Physics, Koc University, Sariyer, Istanbul 34450, Turkey

Abstract

We examine the superradiant (SR) phase transition of Bose-Einstein condensate (BEC) by a Laguerre-Gaussian (LG) beam of higher modes [1, 2]. Unlike the previously existing methods in the literature, we use direct laser simulation and let the spatial profile of SR scattering to evolve self-consistently within the equations of motions. We show that the critical value of the phase transition fits the usual form of quantum phase transition of the Dicke superradiance model. Even though the pump and BEC profiles initially have cylindrical symmetry, it is spontaneously broken into rotational symmetric structures with the occurrence of rotatory SR. This is due to the fact that LG beam transfers its orbital angular momentum to the BEC at once due to the collectivity of SR. At the edges of these rotational structures, multiple vortices are identified, where the number of the vortices depends on the azimuthal mode of the LG beam. At the phase transition, the bosons self-organized themselves, associated with a phase coherence. This self-organization of bosons we observe here is the rotational analog of the experimental findings of Esslinger and colleagues [3].

References

[1] Priyam Das, M.E. Tasgin, and O.E. Mustecaplioglu, *Collectively induced many-vortices topology via rotatory Dicke quantum phase transition,* New J. Phys. **18** 093022 (2016).
[2] M.E. Tasgin, O.E. Mustecaplioglu and L. You, *Creation of Vortex in a Bose-Einstein Condensate by Superradiant Scattering*, Phys. Rev. A 84, 063628 (2011).
[3] K. Baumann, C. Guerlin, F. Brennecke and T. Esslinger, *Dicke Quantum Phase Transition with a Superfluid Gas in an Optical Cavity*, Nature 264, 1301 (2010).

Mapping between charge-monopole and position-dependent mass systems

Anderson L. de Jesus, Alexandre G. M. Schmidt

Departamento de Física de Volta Redonda,
Instituto de Ciências Exatas — Universidade Federal Fluminense,
R. Des. Ellis Hermydio Figueira, 783, Volta Redonda RJ, CEP 27213-415, Brazil

The Physics of magnetic monopoles is quite rich. Despite it was not observed in nature, physicists explore this richness from different point of views: Dirac in a celebrated paper [1] explained electric charge quantization due the presence of magnetic monopoles; Wu and Yang [2] solved the non-relativistic charge-monopole problem exactly and showed physical arguments to eliminate the Dirac string. In the experimental side, there is also plenty of research and the Physics of magnetic monopole was reproduced in spin ice systems [3] as well as in quantum fields [4], synthetic magnetic fields [5] and also using metamaterials [6]. An analogue experimental model of a magnetic monopole was created by Béché and collaborators using a nanoscopically thin magnetic needle[7]. Möttönen and collaborators realized both experimental and computationally an analogue for Dirac monopole using a Bose-Einstein condensate [8].

On the other hand, position-dependent mass (PDM) systems also have a quite rich structure. These PDM systems can model several other quantum systems. The interplay between PDM quantum systems and external magnetic fields was recently studied by Dutra and Oliveira [9], but exact solution for the PDM charge-monopole system is missing in the literature. In this work we fill this gap and look for a PDM system which can exactly reproduce the charge-monopole wavefunctions.

In order to investigate if there exists a PDM quantum system which has the same Physics the charge-monopole has we ask the PDM Schrödinger equation itself, we stick the well-known Wu-Yang wavefunctions $\psi_{WY}(\mathbf{r})$ into the Schrödinger equation and then we obtain a partial differential equation (PDE) for the mass and solve it. We look for a mass distribution $M = M(\mathbf{r})$ which yields, exactly, the $\psi_{WY}(\mathbf{r})$ for the non-relativistic charge-monopole system. Our analogue model for the charge-monopole system is a scalar PDM charged particle — which can also be interpreted as a constant mass charged particle interacting with an effective potential — where the position-dependent mass Schrödinger equation with $M(\mathbf{r})$ is designed to be solved by $\psi_{WY}(\mathbf{r})$.

We study the non-relativistic charge-monopole system when the charged particle has a position-dependent mass $M(r) = m_0 r^w$. We investigate mappings between the charge-monopole system with constant mass and the charge with a position-dependent mass solving the position-dependent mass Schrödinger equation for the mass distribution.

[1] P. A. M. Dirac, Proc. Roy. Soc. **A 133** (1931) 60.
[2] T. T. Wu, C. N. Yang, Nucl. Phys. **B 107** (1976) 365.
[3] C. Castelnovo, R. Moessner, S. L. Sondhi, Nature **451** (2008) 42.
[4] M. W. Ray, E. Ruokokoski, K. Tiurev, M. Möttönen, D. S. Hall, Science **348** (2015) 544.
[5] M. W. Ray, E. Ruokokoski, S. Kandel, M. Möttönen, D. S. Hall, Nature **505** (2014) 657.
[6] J. Wang, S. Qu, Z. Xu, A. Zhang, H. Ma, J. Zhang, H. Chen, M. Feng, Photonics and Nanostructures **12** (2014) 429.
[7] A. Béché, R. van Boxem, G. van Tendeloo, J. Verbeeck, Nature Phys. **10** (2014) 26.
[8] T. Ollikainen, K. Tiurev, A. Blinova, W. Lee, D.S.Hall, M. Mötönen, Phys. Rev. **X 7** (2017) 021023.
[9] A. S. Dutra, J. A. de Oliveira, J. Phys. **A 42** (2009) 025304.

Dynamic and static properties of bosonic dipolar bilayers: reconstruction of density response functions using the sum-rules and stochastic optimization

A. Filinov[1,2,3]

[1] *Christian-Albrechts-Universitt Kiel, Institut fr Theoretische Physik und Astrophysik*
[2] *INP Greifswald e.V., Felix-Hausdorff-Strae 2, 17489 Greifswald*
[3] *Joint Institute for High Temperatures RAS, Izhorskaya Str. 13, 125412 Moscow*

We consider a two-component 2D dipolar bosonic system in the bilayer geometry. By performing quantum Monte Carlo simulations [1] we analyze in detail static distribution functions, kinetic and interaction energies as a function of the interlayer distance. By reducing the layer distance and increase of the interlayer coupling we, finally, observe formation of the dimer states. This transition is accompanied by pronounced changes in the static properties, the off-diagonal (quasi)long-range order (superfluid response), as well as in the spectrum of collective density modes.

The diagonal and off-diagonal components of the dynamic structure factor $S_{\alpha,\beta}(\omega, q)$ are reconstructed from the imaginary time density response functions via the stochastic optimization method [1]. During the reconstruction several power-moments are satisfied exactly.

The excitation spectrum undergoes a gradual transition between three regimes: i) for large layer separations two independent single-layer spectra, ii) for intermediate distances a strongly hybridized spectrum with two characteristic in-phase and out-of-phase modes, iii) single-layer-like spectrum of quasi-particles (double mass and dipole moment) when a strongly bound dimer states are formed.

The dispersion law for the in-phase and out-of-phase collective modes during this crossover is studied in detail and compared with the predictions based on the sum rules formalism [2, 3].

[1] A. Filinov, Phys. Rev. A **94**, 013603 (2016).
[2] K.I. Golden, G.J. Kalman, Phys. Rev. E **88**, 033107 (2013).
[3] Yu.E. Arkhipov, A. Askaruly, D. Ballester, A.E. Davletov, I.M. Tkachenko, G. Zwicknagel, Phys. Rev. E **81**, 026402 (2010).

Explanation of non-linear in-plane resistivity and Hall coefficient in the normal state of cuprates: polaronic approach

O.K. Ganiev

Institute of Nuclear Physics, Uzbekistan Academy of Sciences, Ulugbek, Tashkent 100214, Uzbekistan

We present a theoretical study of the in-plane resistivity $\rho_{ab}(T)$ and Hall coefficient $R_H(T)$ within the polaronic model and precursor pairing scenario by considering a two-component charge carrier picture in the normal state of high-temperature superconducting cuprates (HTSC). Here we use a Boltzmann-equation approach and extended BCS-like model to compute $\rho_{ab}(T)$ and $R_H(T)$ in the τ-approximation. The opening of the pseudogap (PG) in the normal state of the cuprates should affect their transport properties. We have found that the transition to the PG regime and the effective conductivity of charge carriers in the normal state are responsible for the pronounced non-linear temperature dependence of ρ_{ab} and R_H. With the two-component model analysis, we conclude that the opening of the BCS-like PG, while the non-linear temperature dependence of ρ_{ab} and R_H could be understood as a consequence of pairing fluctuations in the PG state of cuprate superconductors. The calculated results for $\rho_{ab}(T)$ and $R_H(T)$ and were compared with the experimental data obtained for various hole-doped cuprates. For all the considered cases, a good quantitative agreement was found between theory and experimental data. We also show that the energy scales of the binding energies of charge carriers are identified by PG crossover temperature on the cuprate phase diagram.

Order-by-disorder in the XY highly frustrated honeycomb lattice under an external magnetic field

F. A. Gómez Albarracín[1] **and H. D. Rosales**[1]

[1] *Instituto de Física de La Plata - FCE-UNLP-CONICET and Departamento de Física, FCE-UNLP, La Plata, Argentina*

In the last year, the honeycomb iridates have been greatly studied since they are candidates to showing Kitaev interactions. Experimental results show that other additional interactions are at play, and for example Heisenberg and further neighbour Kitaev interactions have been suggested and studied [1]. Recently, the classical case of the highly frustrated honeycomb lattice was presented in connection to these models [2]. For Heisenber spins, this model shows a remarkable feature: it is a classical spin liquid with "pinch points" in the structure factor but with a non-bipartite dual lattice. For XY spins, order by disorder is at play, also showing particular features in the structure factor. In this work, we study the classical honeycomb lattice at the maximally frustrated point $J_1/2 = J_2 = J_3$ for XY spins under an external magnetic field. At low enough temperatures thermal fluctuations select a sub-manifold of states. In particular, there are two collinear pseudoplateaux at $M = 1/3$ and $M = 2/3$. The low temperature states are characterized through several and different order parameters, since the system is organized in plaquettes that retain some degeneracy. For higher values of the magnetic field the order parameters show a Z_6 distribution.

[1] S. M. Winter, A. A. Tsirlin, M. Daghofer, J. van den Brink, Y. Singh, P. Gegenwart, R. Valenti, preprint arxiv/1706.06113 (2017).

[2] J. Rehn, A. Sen, K. Damle and R. Moessner, Phys. Rev. Letters **117**, 16 (2016).

Abstract preparation for Conference on "Frontiers in Two-Dimensional Quantum Systems"

F. Heydarinasab and J. Abouie

Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran

We introduce an inhomogeneous hardcore Bose Hubbard model composed of two kinds of boson with different nilpotency conditions and different structures.
By mapping the bosonic mixture to an anisotropic inhomogeneous spin model in the presence of a magnetic field, we study the ground state phase diagram of the model by means of cluster mean field theory[1] and linear spin wave theory and show that various phases such as solid, superfluid, supersolid and Mott insulator appear in the phase diagram of the mixture. Competition between the interactions and magnetic field causes the mixture to undergo different kinds of first and second order phase transitions. By studying the behavior of the spin wave excitations we find the reasons of all first and second order phase transitions.
We also obtain the temperature phase diagram of the system using cluster mean field theory.

[1] D. Yamamoto, A. Masaki, and I. Danshita, Phys. Rev. B **86**, 054516 (2012).

A Brief Review on the Properties of the Spin-1 Ising-Heisenberg Diamond Chain Models

V.V. Hovhannisyan, N.S. Ananikian

A.I. Alikhanyan National Science Laboratory, Alikhanian Br. 2, 0036 Yerevan, Armenia

We study the properties of the exactly solvable spin-1 Ising-Heisenberg diamond chain models using the transfer matrix method [1, 2, 3, 4]. In particular, exact results for the ground state, magnetization process, specific heat, partition function zeros and thermal entanglement are presented. The contributions of the single-ion anisotropy, bilinear XXZ Heisenberg, biquadratic XXZ- and Ising-Ising interaction parameters into the properties of the models are discussed. As we show, the magnetization curves may include either one, two or three intermediate magnetization plateaus at zero, one-third and two-thirds of the saturation magnetization.

[1] N.S. Ananikian, J. Strečka, V. Hovhannisyan, Solid State Commun. **194**, 48 (2014).
[2] V.S. Abgaryan, N.S. Ananikian, L.N. Ananikyan, V.V. Hovhannisyan, Solid State Commun. **224**, 15 (2015).
[3] V.V. Hovhannisyan, N.S. Ananikian, R. Kenna, Physica A **453**, 111 (2016).
[4] V.V. Hovhannisyan, J. Strečka, N.S. Ananikian, J. Phys.: Condens. Matter **28**, 085401 (2016).

Functional renormalization group methods for low-dimensional spin systems

Yasir Iqbal[1], **Ronny Thomale**[2], **and Johannes Reuther**[3]

[1] *Department of Physics, Indian Institute of Technology Madras, Chennai-600036, India*
[2] *Institute of Theoretical Physics and Astrophysics, Julius-Maximilian's University of Würzburg, Würzburg D-97074, Germany*
[3] *Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, D-14195 Berlin, Germany and Helmholtz-Zentrum Berlin für Materialien und Energie, D-14109 Berlin, Germany*

The investigation of low dimensional quantum spin systems in the strongly correlated regime represents one of the most challenging problems in condensed matter theory. I will present recent advances made using Pseudo-fermion functional renormalization group methods towards understanding the low-temperature physics of highly frustrated magnetic systems where strong quantum fluctuations lead to novel ground states such as quantum spin liquids.

[1] Yasir Iqbal, Ronny Thomale, Francesco Parisen Toldin, Stephan Rachel, and Johannes Reuther., Phys. Rev. B. **94**, 140408(R) (2016)

Superconductivity, charge-density waves, and antiferromagnetism in the Hubbard-Holstein model

Seher Karakuzu,[1] Luca F. Tocchio,[2] Sandro Sorella,[1] and Federico Becca[3]

[1] *SISSA-International School for Advanced Studies, Via Bonomea 265, I-34136 Trieste, Italy*
[2] *Institute for condensed matter physics and complex systems, DISAT, Politecnico di Torino, I-10129, Italy*
[3] *Democritos National Simulation Center, Istituto Officina dei Materiali del CNR and SISSA-International School for Advanced Studies, Via Bonomea 265, I-34136 Trieste, Italy*

(Dated: September 14, 2017)

By using variational wave functions and quantum Monte Carlo techniques, we investigate the interplay between electron-electron and electron-phonon interactions in the two-dimensional Hubbard-Holstein model. Here, the ground-state phase diagram is triggered by several energy scales, i.e., the electron hopping t, the on-site electron-electron interaction U, the phonon frequency ω_0, and the electron-phonon coupling g. At half filling, the ground state has antiferromagnetic order for $U \gtrsim 2g^2/\omega_0$, while it shows charge-density waves for $U \lesssim 2g^2/\omega_0$. In addition to these phases, for $\omega_0/t = 1$, we find that a superconducting phase emerges when both U/t and $2g^2/t\omega_0$ are small. Then, by increasing the value of the phonon energy, superconductivity extends along the transition line between antiferromagnetic and charge-density-wave insulators. Away from half filling, phase separation occurs when doping the charge-density-wave insulator, while a uniform (superconducting) ground state is found when doping the superconducting phase. In the analysis of the finite-size effects, it is extremely important to average over over twisted boundary conditions, especially in the weak-coupling limit and/or in the doped case.

Interplay of Dimensionality, Interaction and Disorder in Two-Dimensional Fermi Systems

Ayan Khan[1], **B. Tanatar**[1,2]

[1] *Department of Physics, SEAS, Bennett University, Greater Noida, 201310, India*
[2] *Department of Physics, Bilkent University, Ankara, 06800, Turkey*

We study the two-dimensional (2D) ultracold Fermi gas with weak impurity in the framework of mean-field theory where the impurity is introduced through Gaussian fluctuations [1]. Our investigation reveals a unique manifestation of lower dimensionality in the interaction-disorder face-off. We have also noted the characteristic difference between the two dimensional s-wave scattering length and three dimensional s-wave scattering length and its implication on the dirty environment. To support our observations we have studied some of the experimentally accessible quantities such as condensate fraction and equation of state.

[1] A. Khan, B. Tanatar, Int. J. Mod. Phys. B **31**, 1750066 (2017).

Anderson metal-insulator transition and pseudogap phenomena in underdoped cuprates

Khudayberdiev Z.S.

Institute of Nuclear Physics, 100214, Tashkent, Uzbekistan
e-mail: zafar-uzb@mail.ru

As is well known, the undoped copper oxides (cuprates) are antiferromagnetic (AF) insulators and a small level of doping (e.g., $x = 0.02$ in $La_{2-x}Sr_xCuO_4$ (LSCO)) leads to the disappearance of AF order, the material undergoes a transition from an AF insulator to an unusual insulator. By further doping, these compounds undergo insulator-to-metal transitions and they exhibit an anomalous metallic behavior in the underdoped region [1-3]. The existence of a normal-state gap (or pseudogap (PG)) in the excitation spectrum of the underdoped cuprates was also observed in many experiments [3-5]. In this work we first examine the localization of carriers near the lattice defects (impurities), the conditions under which the metal-insulator transition (MIT) due to the strong structural disorder occurs in doped material. The conditions for carrier localization or delocalization can be obtained by using the uncertainty relation $\Delta y \Delta p \geq \hbar/2$ where Δp and Δy are the uncertainties in the momentum and coordinate of a carrier, respectively. This uncertainty relation can be written as [6]

$$\Delta y \Delta E = \frac{(\hbar \Delta k)^2}{2m^*} \frac{1}{2\Delta k} = \frac{W_I a_I}{4}, \tag{1}$$

where ΔE and Δk are the uncertainties in the energy and wave vector of the carrier, m^* is the effective mass of carriers, W_I is the width of the impurity band, a_I is the lattice parameter of the superlattice of such defects.

When the impurity centers having the radius R_I are distributed randomly the disorder-indused spatial localization of carriers can drive the Anderson-type MIT in the cuprates. Taking into account that a random potential V_0 leads to the uncertainties in the energy $\Delta E \sim V_0/2$ and coordinate $\Delta y \sim R_I$ of carriers, we can write the condition for Anderson localization in the form

$$\frac{V_0}{W_I} \geq \frac{a_I}{2R_I}. \tag{2}$$

One can assume that V_0 would be of the order of $2E_I$ where E_I is the binding energy of carriers bound to impurities. If the impurity centers form a simple cubic superlattice with $a_I > 2R_I$, the criterion for the Anderson MIT can be written as

Wave-packet dynamics of Bogoliubov quasiparticles: Quantum metric effects

Long Liang, Sebastiano Peotta, and Ari Harju, and Päivi Törmä

Department of Applied Physics, Aalto University, Fi-00076 Aalto, Finland

We study the dynamics of the Bogoliubov wave packet in superconductors and calculate the supercurrent carried by the wave packet. We discover an anomalous contribution to the supercurrent, related to the quantum metric of the Bloch wave function. This anomalous contribution is most important for flat or quasiflat bands, as exemplified by the attractive Hubbard models on the Creutz ladder and sawtooth lattice. Our theoretical framework is general and can be used to study a wide variety of phenomena, such as spin transport and exciton transport.

[1] L. Liang, S. Peotta, and A. Harju, and P. Törmä, Phys. Rev. B 96, 064511 (2017).

Two-Dimensional Homogeneous Fermi Gases

Klaus Hueck[1], **Niclas Luick**[1] , **Lennart Sobirey**[1], **Jonas Siegl**[1], **Thomas Lompe**[1], **and Henning Moritz** [1]

[1] *Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany.*

Ultracold 2D Fermi gases allow to precisely characterize the interplay of a reduced dimensionality and strong interactions in a quantum many body system. So far, ultracold 2D Fermi gases have been studied in harmonic trapping potentials, which gives rise to an inhomogeneous density distribution. This complicates the interpretation of non-local quantities like correlation functions and the momentum distribution, which can only be extracted as trap-averaged quantities. In addition, the inhomogeneous density distribution reduces the chance of creating quantum phases which are predicted to exist in only small regions of the phase diagram.
Here, we report on the experimental realization of homogeneous 2D Fermi gases trapped in a box potential. The radial confinement is realized by a ring-shaped blue-detuned beam with steep walls. Additionally, a digital micro mirror device can be used to remove residual inhomogeneities and to imprint arbitrary repulsive potentials onto the system.

Hard Wall Confinements of $\nu = 1/2$ Fractional Quantum Hall Liquids in Disk-shaped and Ring-shaped Geometries

E. Macaluso[1] **and I. Carusotto**[1]

[1] *INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy*

By means of the exact diagonalization method we studied the effect of a hard wall confinement on $\nu = 1/2$ bosonic fractional quantum Hall liquids in the lowest Landau level approximation. As a first step, we focused on the physics characterizing edge and quasi-hole excitations in single-edge disk-shaped geometries. We discovered that excitation spectra of systems experiencing hard wall potentials strongly differ from those associated with harmonically confined systems and that this kind of potentials allows to remove the degeneracy also between edge excitations with the same angular momentum quantum number. An interpretation of the numerical spectra in terms of single Jack polynomials is put forward. We then extended our work to ring-shaped liquids enclosed between two cylindrical hard walls which provide edges with opposite chiralities. Also in this case, we can understand the numerical spectra in terms of Jack polynomials.

[1] E. Macaluso and I. Carusotto, arXiv:1706.00353, (2017).

Brezinskii-Kosterlitz-Thouless transition in disordered superconducting films

I. Maccari[1,2], L. Benfatto[1,2], and C. Castellani[1]

[1] *ISC-CNR and Department of Physics,*
[2] Sapienza University of Rome, P.le Aldo Moro , 00185, Rome, Italy

Despite its age, the Brezinskii-Kosterlitz-Thouless (BKT) transition remains one of the most fascinating examples of topological phase transitions. Its universality class describes several phenomena ranging from the quantum metal-insulator transition in one dimension to the Columb-gas screening transition in 2D, and of course the metal-to-superfluid transition in 2D. Among real systems, the case of quasi-two-dimensional superconductors (SC) is particularly interesting because of the interplay between the vortex-unbinding transition and the electron inhomogeneity, which spontaneously emerges in thin SC films. Indeed, although the BKT transition is usually protected against disorder, its fingerprints in real system, like e.g the universal superfluid-density jump, are often at odd with this expectation. In this work we have shown, by means of Monte Carlo simulations, that the disorder-induced granularity of the superconducting state modifies the nucleation mechanism for vortex-antivortex pairs leading to a considerable smearing of the universal superfluid-density jump as compared to the paradigmatic clean case, in agreement with experimental observations.
Finally, we have extended our study in the presence of a transverse magnetic field focusing both on its effects on the fragmentation of the SC order parameter (effect partially similar to increasing the disorder strength) and on the superfluid density transition.

[1] **arXiv:1702.05930 (2017)** I. Maccari, L. Benfatto, C. Castellani. *Broadening of the Berezinskii-Kosterlitz-Thouless transition by correlated disorder*

Crucial Role of Internal Collective Modes in Underdoped Cuprates

Aabhaas V. Mallik[1], **Umesh K. Yadav**[1], **Amal Medhi**[2], **H. R. Krishnamurthy**[1], **Vijay B. Shenoy**[1]

[1] *(Presenting author underlined) Indian Institute of Science, Bengaluru, India - 560012*
[2] *Indian Institute of Science Education and Research, Thiruvananthapuram, India - 695016*

The enigmatic cuprate superconductors have attracted resurgent interest with several recent reports and discussions of competing orders in the underdoped side. Motivated by this, here we address the natural question of frality of the d-wave superconducting state in underdoped cuprates. Using a combination of theoretical approaches we study t-J like model, and discover an – as yet unexplored – instability that is brought about by an "internal" (anti-symmetric mode) fluctuation of the d-wave state. This new theoretical result is in good agreement with recent STM[1, 2] and ARPES[3, 4] studies of cuprates. We also suggest experimental directions to uncover this physics.

[1] Yang He *et. al.*, Science **344**, 604 (2014).
[2] M. J. Lawler *et. al.*, Nature **466**, 347 (2010).
[3] I. M. Vishik *et. al.*, PNAS (doi: 10.1073), 1209471109 (2012).
[4] E. Razzoli *et. al.*, PRL **110**, 047004 (2013).

Quantum phases and collective excitations of a spin-orbit-coupled Bose-Einstein condensate in a one-dimensional optical lattice

G. I. Martone[1], **T. Ozawa**[2], **C. Qu**[2], **and S. Stringari**[2]

[1]*LPTMS, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay, France*
[2]*INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, I-38123 Povo, Italy*

The ground state of a spin-orbit-coupled Bose gas in a one-dimensional optical lattice is known to exhibit a mixed regime, where the condensate wave function is given by a superposition of multiple Bloch-wave components, and an unmixed one, in which the atoms occupy a single Bloch state. The unmixed regime features two unpolarized Bloch-wave phases, having quasimomentum at the center or at the edge of the first Brillouin zone, and a polarized Bloch-wave phase at intermediate quasimomenta. By calculating the critical values of the Raman coupling and of the lattice strength at the transitions among the various phases, we show the existence of a tricritical point where the mixed, the polarized and the edge-quasimomentum phases meet, and whose appearance is a consequence of the spin-dependent interaction. Furthermore, we evaluate the excitation spectrum in the unmixed regime and we characterize the behavior of the phonon and the roton modes, pointing out the instabilities occurring when a phase transition is approached.

[1] G. I. Martone, T. Ozawa, C. Qu, and S. Stringari, Phys. Rev. A **94**, 043629 (2016).
[2] G. I. Martone, submitted to J. Low Temp. Phys.

Anomalous transport near the Lifshitz transition at the $LaAlO_3/SrTiO_3$ interface

S. Nandy[1], **N. Mohanta**[2], **S. Acharya**[3], **and A. Taraphder**[1,4]

[1] *Department of Physics, Indian Institute of Technology Kharagpur, W.B. 721302, India*
[2] *Center for Electronic Correlations and Magnetism, Theoretical Physics III, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany*
[3] *Kings College London, London WC2R 2LS, United Kingdom*
[4] *Centre for Theoretical Studies, Indian Institute of Technology Kharagpur, W.B. 721302, India*

The quasi two-dimensional electron liquid (q2DEL), at the (001) interface between band insulators $LaAlO_3$ and $SrTiO_3$, undergoes Lifshitz transition as the interface is doped with carriers. At a critical carrier density, two new orbitals populate the Fermi level, with a concomitant changes in the Fermi surface topology. Using dynamical mean-field theory, formulated within a realistic three-orbital model, we study the influence of the Lifshitz transition (LT) and local electron correlations on the electronic and transport properties, viz., thermal conductivity, optical conductivity, Seebeck coefficient and angle resolved photoemission spectra. We find that at a critical density, both the thermal and dc conductivities rise sharply while the Seebeck coefficient shows a cusp. The inter-orbital electron-electron interaction transfers spectral weight near the Γ point towards lower energy, thereby reducing the critical density for LT. In the presence of external magnetic field, the critical density further reduces due to exchange splitting. Beyond a sufficiently large field, multiple cusps appear in the Seebeck coefficient revealing multiple LT. The q2DEL shows another intriguing phenomenon at the interface - a positive magnetoconductance (MC), i.e. decrease in electrical resistance in the presence of parallel electric ($\mathbf{E}$) and magnetic ($\mathbf{B}$) fields (i.e., $\mathbf{E} \times \mathbf{B} = 0$, the conventional magnetoresistance vanishes). Interestingly, the MC undergoes a change of sign from negative to positive by tuning the gate voltage. The physical origin of this novel phenomenon at the interface is still unclear. In this work we use multi-orbital dynamical mean-field theory (MO-DMFT), formulated within a realistic three-orbital model, and calculate the longitudinal MC using Kubo-Greenwood formula. We show that the Rashba spin-orbit coupling and the multi-orbital scattering play significant roles in determining MC.

[1] A. Joshua, J. Ruhman, S. Pecker, E. Altman and S. Ilani, Proceedings of the National Academy of Sciences **110**, 9633 (2013).
[2] S. Nandy, N. Mohanta, S. Acharya, and A. Taraphder, Phys. Rev. B **94**, 155103 (2016).
[3] M. Diez, A. M. R. V. L. Monteiro, G. Mattoni, E. Cobanera, T. Hyart, E. Mulazimoglu, N. Bovenzi, C.W. J. Beenakker, and A. D. Caviglia Phys. Rev. Lett. **115**, 016803 (2015).
[4] A. D. Caviglia, M. Gabay, S. Gariglio, N. Reyren, C. Cancellieri and J. M. Triscone, Phys. Rev. Lett. **104**, 126803 (2010).
[5] F. J. Wong, R. V. Chopdekar and Y. Suzuki, Phys. Rev. B **82**, 165413 (2010).
[6] A. Annadi, Z. Huang, K. Gopinadhan, X. R. Wang, A. Srivastava, Z. Q. Liu, H. H. Ma, T. P. Sarkar, T. Venkatesan and Ariando, Phys. Rev. B **87**, 201102 (2013).

Influence of transition metal doping on the electronic and optical properties of ReS2 and ReSe2 monolayers

Kingsley Onyebuchi Obodo, Cecil Napthaly Moro Ouma, Joshua Tobechukwu Obodo and Moritz Braun.

We investigate the structural, electronic and optical properties of transition metal doped triclinic monolayered rhenium disulfide and diselenide (ReS2 and ReSe2) by means of quantum mechanical calculations. The calculated electronic band gaps for ReS2 and ReSe2 monolayers are 1.43 eV and 1.23 eV, respectively, with both having a non-magnetic ground state. The calculated dopant substitutional energies under both Re-rich and X(S or Se)-rich conditions show that it is possible to experimentally synthesize transition metal doped ReX2 (where X is S or Se) monolayer systems. We found that the presence of dopant ions (such as V, Cr, Mn, Fe Co, Nb, Mo, Ta and W) in the ReS2 and ReSe2 monolayers significantly modifies their electronic ground states with consequent introduction of defect levels and modification of the density of states profile. However, it was found that Mn doped structures show a very minute reduction of the electronic band gap. We found that a ferro- or a non- magnetic ground state configuration was obtained depending on the choice of dopant ions in ReS2 and ReSe2 monolayers. Cr, Fe and Co doping result in a ferro-magnetic ground state configuration of the ReX2 structures. The calculated absorption and reflectivity spectra show that this class of dopants causes a general increase in the absorption spectral peaks but only a minute influence on the reflectivity. Optical anisotropy was observed depending on whether the direction of polarization in the xy-plane is either parallel or perpendicular.

STRONGLY CORRELATED FOUR ELECTRON SYSTEMS AWAY FROM HALF FILLING

O.E. OSAFILE[1], J. O. Azi[1] and J.O.A. Idiodi[2]

[1]Department of Physics, Federal University of Petroleum Resources, Effurun,
[2]Department of Physics, University of Benin, Benin City.
E-mail: osafile.omosede@fupre.edu.ng

ABSTRACT

Strong correlation of interacting electrons has been widely studied under the single band Hubbard model with the aid of several techniques. These numerous studies have been carried out at different band filling. In this work, the ground state energy away from half filling in one dimension is studied employing a simplified modification of the Lanczos technique with particular interest in how the ground state energy affects anti-ferromagnetism. Several interaction strengths are considered both in the positive u limit and negative u limit and the interesting case of no interaction.

Second Sound in Two-Dimensional Bose Gas: From Weakly Interacting Regime to Strongly Interacting Regime

M. Ota[1], **S. Stringari**[1]

[1] *INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, Italy*

Second sound is a phenomenon arising from the two-fluid nature of a superfluid, corresponding to an entropy wave in which the normal component and the superfluid component oscillate in opposite phases, propagating with a velocity which is directly related to the superfluid fraction.
In this work, we theoretically investigate first and second sound propagating in a uniform two-dimensional Bose gas, using Landau's theory of two-fluid hydrodynamics [1] and universal thermodynamics [2]. We study the temperature and interaction strength dependence of both sound modes and show that their behavior substantially changes as the gas evolves from the weakly interacting to the strongly interacting regime. In particular, we find that observation of second sound from a density perturbation of the system becomes more difficult as the interaction strength increases. We show that the behavior of sound modes, including the discontinuity of both velocities at the critical temperature arising from the Berezinskii-Kosterlitz-Thouless jump of the superfluid density [3], is closely related to the thermal expansion coefficient.
Since second sound provides information about the superfluid density, our results would be useful for the experimental measurement of the superfluid density in two-dimensional quantum gases, a purpose which has not been realized so far.

[1] L. D. Landau, J. Phys. USSR, **5**, 71 (1941).
[2] N. Prokof'ev, B. Svistunov, Phys. Rev. A., **66**, 043608 (2002).
[3] J. M. Kosterlitz, D. J. Thouless, J. Phys. C, **6**, 1181 (1973).

On the mode evolution study of segregated condensate mixtures in quasi-2D confinement

We present new features of low energy Bogoliubov quasiparticle excitations of a two component Bose-Einstein condensate (TBEC) in quasi-2D geometry at zero temperature using Hartree-Fock-Bogoliubov (HFB) formalism. We, in particular, consider the TBECs of ^{85}Rb -^{87}Rb, and show specific features in the low energy excitation spectrum as a function of the interaction strength. The appearance of a new zero energy mode is observed due to the growth of dynamic instability in the system. Also We study the effect of anisotropic trap geometry on the low energy Bogoliubov quasiparticle excitations of ^{85}Rb -^{87}Rb TBEC at zero temperature. We show that the introduction of radial anisotropy modifies the structure of the interface from circular to planar.

PACS numbers: 03.75.Mn,03.75.Hh,67.60.Bc,67.85.Bc

Structural, electric and transport properties of borophene and fully hydrogenated borophene within density functional theory

Mansoureh Pashangpour*

Department of Physics, Islamshahr Branch, Islamic Azad University, Islamshahr, Iran

Borophene, monolayer of boron atoms, is a new two-dimensional structure that recently has attracted attentions. I have investigated borophene and two structure of borophane, fully hydrogenated borophene, using density functional theory with generalized gradient approximation. Structure, projected density of states, charge transfer, bandstructure, Fermi velocity, current-voltage diagrams and quantum conductance of borophene and borophane are studied and compared. The results show that borophene and table-like borophane are metal and chair-like borophane is a semimetal with linear dispersion relation near Fermi Energy. Also, the current-voltage characteristics show Ohmic behavior. Boron atoms of borophane are donor and hydrogen atoms are acceptor. High Fermi velocity in chair-like borophane makes it suitable for application in nanoelectronic devices.

[1]Z. Wang, T.-Y. Lü, H.-Q. Wang, Y.-P. Feng, J.-C. Zheng, ' High anisotropy of fully hydrogenated borophene' Physical Chemistry Chemical Physics, vol. 18, pp. 31424, 2016.
[2]José Eduardo Padilha, Roberto Hiroki Miwa and Adalberto Fazzio, ' Directional dependence of the electronic and transport properties of 2D borophene and borophane' Phys. Chem. Chem. Phys., vol. 18, pp. 25491-25496, 2016.

Orbital Magnetic Field on Correlated Systems in Two Dimensions

Subhasree Pradhan

Department of Physics, Indian Institute of Technology Kharagpur, Kharagpur-721302, West Bengal, India

Non-interacting lattice fermions in a two-dimensional lattice under the presence of strong magnetic field are found to behave strangely: a *Hofstadter butterfly* spectrum, a fractal structure in quantum mechanics, arises. The spectrum depends critically [1] on the ratio $\alpha = p/q$; p and q are positive integers, the ratio of the magnetic flux per plaquette to the flux quantum). If $\frac{p}{q}$ is a rational number, each energy band is split into q subbands by the magnetic field, revealing a recursive structure. What happens to this fractal structure in a non-bipartite lattice such as triangular lattice and in presence of Coulomb interaction (U)? We present one such example [1]. The magnetic field induces a charge-gap (largest at $\alpha = 0.5$) even in the absence of correlation, highlighting localization by orbital magnetic field. Remarkably, this gap is initially suppressed by correlation (zero at $\alpha = 0.5$) and reappears for larger U in the Falicov-Kimball model (FKM). In an extended FKM, the condensation of preformed exciton is affected by competing terms α, U and hybridization V: interaction U exponentially enhances [2,3,4] the excitonic average (Δ), field α has a localizing effect leading to a drop in Δ. Although, in the small V limit there is different role of orbital field which favours the formation of an exciton at $\alpha = 1/3$ per plaquette, thereby opening the possibility of tuning ferro-electricity via magnetic field. We investigate the orbital effects of a strong external magnetic field on the ground-state properties of a two-dimensional (2D) Holstein polaron, employing variational approaches based on exact diagonalization. From the ground-state energy and the wave function, we calculate the electron-phonon correlation function, the average phonon number, and the Drude weight and investigate the evolution of a 2D Holstein polaron as a function of the magnetic flux. Although the external magnetic field affects the polaron throughout the parameter regime, we show that the magnetic field has a stronger effect on a loosely bound (spatially extended) polaron [5]. We also find that the magnetic field can be used as a tuning parameter, particularly for a weakly coupled polaron, to reduce the spatial extent of a large polaron.

[1] S. Pradhan; J. Phys.: Condens. Matter **28** 505502 (12pp) (2016).
[2] S. Pradhan and A. Taraphder; Europhysics Letters, **116**, 57001 (2016).
[3] S. Pradhan and A. Taraphder; Journal of Physics: Conference Series **759** 012032 (2016).
[4] S. Pradhan and A. Taraphder; arXiv:1707.04701.
[5] S. Pradhan, M. Chakraborty and A. Taraphder; Phys. Rev. B **93**, 115109 (2016).

Ground state of the two-dimensional Fermi gas: Essential properties from few to many body

Lukas Rammelmüller[1], **William J. Porter**[2], **Jens Braun**[1], **and Joaquín E. Drut**[2]

[1] *Institut für Kernphysik (Theoriezentrum), TU Darmstadt, D-64289 Darmstadt, Germany*

[2] *Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC, 27599, USA*

We calculate ground-state properties of fermions on a two-dimensional square lattice in the range from few to many particles. Using first-principles *quantum Monte Carlo (QMC)* methods, we determine the ground-state energy, Tan's contact, momentum distribution, and single-particle correlation function. We investigate those properties for systems of $N = 2, 4, \cdots, 20$ particles per spin flavor and for a wide range of attractive couplings. Extending these valuable insights towards spin-polarized and mass-imbalanced fermions proves to be a challening task, as QMC methods are subject to a sign problem in these cases. To address this issue, we present a *Complex Langevin (CL)* approach to tackle such systems based on recent methodological developments.

[1] L. Rammelmüller, W.J. Porter, J.E. Drut, Phys. Rev. A **93**(3), 033639 (2016).
[2] L. Rammelmüller, W.J. Porter, J.E. Drut, J. Braun, arXiv:1708.03149.

Dynamical Electrical Conductivity of Graphene

Luxmi Rani[1] **and Navinder Singh**[1]

[1] *Theoretical Physics Division, Physical Research Laboratory, Ahmedabad-380009, India.*

For graphene, it has been theoretically predicted and experimentally observed that DC resistivity is proportional to T^4 when the temperature is much less than Bloch-Grüneisen temperature (Θ_{BG}) and T-linear in opposite case ($T \gg \Theta_{BG}$) [1, 2, 3, 4, 5]. Going beyond this case, we investigate the dynamical electrical conductivity in graphene using the powerful methods the memory function formalism [6]. In the zero frequency regime, we obtain the above mentioned behavior which was previously obtained using the Bloch-Boltzmann kinetic equation. In the finite frequency regime, we obtain several new results: (1) the generalized Drude scattering rate, in the zero temperature limit, shows ω^4 behavior at low frequencies ($\omega \ll k_B\Theta_{BG}/\hbar$) and saturates at higher frequencies. We also observed the Holstein mechanism, however, with different power laws from that in the case of metals; (2) At higher frequencies, $\omega \gg k_B\Theta_{BG}/\hbar$, and higher temperatures $T \gg \Theta_{BG}$, we observed that the generalized Drude scattering rate is linear in temperature. In addition, several other results are also obtained. With the experimental advancement of this field, these results should be experimentally tested.

[1] S. D. Sarma , S. Adam, E. H. Hwang, E. Rossi, Rev. Mod. Phys. **83**, 407 (2011)
[2] D. K. Efetov, P. Kim, Phys. Rev. Lett. **105**, 256805 (2010)
[3] E. Muñoz, J. Phys.: Condens. Matter **24**, 195302 (2012)
[4] E. H. Hwang, S. D. Sarma, Phys. Rev. B **77**, 115449 (2008).
[5] K. Kaasbjerg, K. S. Thygesen, K. W. Jacobsen, Phys. Rev. B **85**, 165440 (2012).
[6] N.Singh, Electronic Transport Theories: From Weakly to Strongly Correlated Materials, Taylor and Francis Group, CRC Press (2016).

Finite temperature expansion dynamics of annular condensates

Arko Roy[1,2], **D. Angom**[1]

[1] *Physical Research Laboratory, Navrangpura, Ahmedabad-380009, Gujarat, India*
[2] *Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany*

We explore the effects of finite temperature on the dynamics of Bose-Einstein condensates (BECs) after it is released from the confining potential. In addition, we examine the variation in the expansion dynamics of the BECs as the confining potential is transformed from a multiply to a simply connected geometry. To include the effects of finite temperatures we use the frozen thermal cloud approximation, and observe unique features of the condensate density distribution when released from the confining potential. We find that at $T \neq 0$, during the initial stages of expansion, the multiply connected condensate has more pronounced interference rings compared to the case of zero temperature. Such difference in the dynamical evolution is also evident for simply connected condensates.

[1] A. Roy and D. Angom, Phys. Lett. A **381**, 2483 (2017).
[2] A. Roy and D. Angom, New J. Phys. **18**, 083007 (2016).

Quantum Monte Carlo study of excitons and biexcitons in mass-asymmetric electron-hole bilayer

Rajesh O. Sharma, L. K. Saini, and Bhagwati Prasad Bahuguna

[1] *(Presenting author underlined) Applied Physics Department, Sardar Vallabhbhai National Institute of Technology Surat, India-395007*

We have employed the diffusion Monte Carlo method, under fixed node approximation, to investigate various ground state properties of mass-asymmetric electron-hole bilayer system. Particularly, we have calculated the ground state energy, the condensation fraction c and the pair correlation function g(r) at density $r_s = 5$ a.u. for inter-planer distance $d \leq 0.5$ a.u. Based on the characteristics of condensate faction and pair correlation functions, we found the phase transition from excitonic fluid phase to biexcitonic fluid phase at $d = 0.24$ a.u. Also, we have analytically calculated critical layer separation d_{crit} for biexciton stability whose value was almost double than the $d = 0.24$ a.u.

Impurity scattering on the surface of topological insulator thin films

M. Shiranzaei[1], F. Parhizgar[2], J. Fransson[3] and H. Cheraghchi[1]

[1] *School of Physics, Damghan University, P.O. Box 36716-41167, Damghan, Iran*
[2] *School of Physics, Institute for Research in Fundamental Sciences (IPM), Tehran 19395-5531, Iran*
[3] *Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 21, Uppsala, Sweden*

Quantum anomalous Hall (QAH), theoretically predicted in Ref. [5], was experimentally realized in magnetically doped TI thin films [6, 7]. In fact, magnetic ordering in TI thin films leads to a band topology at zero external magnetic field. Although this effect has been confirmed by other experimental groups, the theoretical background especially the mechanism emerging such a ferromagnetism is still under debate [3, 5, 8, 9, 10, 11, 12, 13, 14]. Since the QAH experiment has been done at zero chemical potential, the role of impurity bands in both transport properties and also mechanism of coupling between impurities is of much importance when the chemical potential lies inside the gap.
We address the electronic structure of the surface states of topological insulator thin films with embedded local non-magnetic and magnetic impurities. By using the T-matrix [1, 2, 4, 15, 16, 17] to obtain the local density of electrons states and corresponding spin resolved densities, we find that a sufficiently strong potential associated with the single impurity generates states inside the gap. Hence, for many impurities with different potentials one can expect the gap to be filled or, at least, strongly modified [3, 4]. We show that the effects of the impurities can be tuned by applying an electric field between the surface layers. The emerging magnetic states are expected to play an important role both in ferromagnetic mechanism of magnetic topological insulators as well as in its transport properties. The existence of these new states becomes more important when one considers their relaxation time. The relaxation time of the impurity states is proportional to the inverse of their self-energy which in the first Born approximation is proportional to the bare density of states of the system. The appearance of these new peaks inside the gap indicates that they are stable with relatively long life-times compared to bound states outside the gap of materials known as virtual bound states.

[1] Q. Liu, C.-X. Liu, C. Xu, X.-L. Qi and S.-C. Zhang, Phys. Rev. L **102**, 156603 (2009).
[2] J. Fransson, A. M. Black-Schaffer, and A. V. Balatsky, Phys. Rev. B **90**, 241409(R), (2014).
[3] T. R. F. Peixoto, *et, al.*, Phys. Rev. B **94** 195140 (2016).
[4] R. R. Biswas and A. V. Balatsky, Phys. Rev. B **81**, 233405, (2010).
[5] R. Yu, *et, al.*, Science **329**, 61 (2010).
[6] C.-Z. Chang, *et, al.*, Science **340**, 167 (2013).
[7] J. G. Checkelsky, *et, al.* Nat. Phys. **10**, 731 (2014).
[8] P. Larson and W. R. L. Lambrecht, Phys. Rev. B **78**, 195207 (2008).
[9] M. G. Vergniory, *et, al.*, Phys. Rev. B **89**, 165202 (2014).
[10] E. O. Lachman, *et, al.*, Sci. Adv. **1**, el500740 (2015).
[11] M. Li, *et, al.*, Phys. Rev. Lett. **114**, 146802 (2015).
[12] M. Ye, *et, al.*, Nat. Commun. **6**, 8913 (2015).
[13] S. Grauer, *et, al.*, Phys. Rev. B **92**, 201304 (2015).
[14] P. Sessi, *et, al.*, Nat. Commun. **7**, 12027 (2016).
[15] N. M. R. Peres, F. Guinea and A. H. Castro Neto, Phys. Rev. B **73**, 125411 (2006).
[16] A. V. Balatsky, I. Vekhter and J. X. Zhu, Rev. Mod. Phys., Volume **78** (2006).
[17] Y.L. Zou, J. Song, Ch. Bai and Kai Chang Phys. Rev. B **94**, 035431 (2016).

Creating Homogeneous Two-Dimensional Fermi Gases

Lennart Sobirey[1], **Klaus Hueck**[1], **Niclas Luick**[1], **Jonas Siegl**[1], **Thomas Lompe**[1] **and Henning Moritz**[1]

[1] *Institut fuer Laserphysik, Universitaet Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany.*

In this poster we present techniques central to our creation and investigation of homogeneous two-dimensional Fermi gases [1]. To load 2D Fermi gases both in single and double layer configuration, we developed a method to detect the occupation of the different layers in a single shot measurement. A repulsive ring-shaped potential with variable size and height and minimal pertubation inside is crucial to confine the homogeneous gases. This can be achieved with an optical setup employing three axicons. We demonstrate how the in plane momentum distributions can be obtained using matter wave focusing and how spin removal can mitigate interaction effects during time of flight.

Finally, we report on a novel method to calibrate high intensity absorption imaging to high precision using relative measurements of the momentum transferred to the atoms by the imaging light [2].

[1] Klaus Hueck, Niclas Luick, Lennart Sobirey, Jonas Siegl, Thomas Lompe, Henning Moritz, arXiv:1704.06315.

[2] Klaus Hueck, Niclas Luick, Lennart Sobirey, Jonas Siegl, Thomas Lompe, Henning Moritz, Logan W. Clark, Cheng Chin, Opt. Express **25**, 8670-8679 (2017).

Abstract for Conference on "Frontiers in Two-Dimensional Quantum Systems"

K. Suthar[1,2] **and D. Angom**[1]

[1] *Physical Research Laboratory Navrangpura, Ahmedabad-380009, Gujarat, India*
[2] *Indian Institute of Technology, Gandhinagar, Ahmedabad-382424, Gujarat, India*

We examine the ground-state density distributions and collective excitations of two-species Bose-Einstein condensates (TBECs) confined in quasi-two-dimensional (quasi-2D) optical lattices. For this we employ the Hartree-Fock-Bogoliubov theory with Popov approximation in the Bose-Hubbard model to analyze the quasiparticle mode evolution, structure of mode functions and dispersion curves. We observe that the TBECs acquire a side-by-side profile when the system is tuned from miscible to immiscible phase. The quasiparticle energies are softened on approaching phase separation, but harden after the phase separation and mode degeneracies are lifted. The dispersion curve of miscible phase shows a discernible trend due to azimuthal symmetry whereas that is not the case for the immiscible phase [1]. In addition, we show that the thermal fluctuations enhance the miscibility of condensates and at a characteristic temperature the system becomes miscible. The temperature driven immiscible-miscible transition is accompanied by a discontinuity in the excitation spectrum and low-lying quasiparticle modes become degenerate at the characteristic temperature [2].

[1] K. Suthar, D. Angom, Phys. Rev. A **93**, 063608 (2016).
[2] K. Suthar, D. Angom, Phys. Rev. A **95**, 043602 (2017).

Density-Wave Instability and Collective Modes in Bilayer Dipolar Systems

B. Tanatar[1], **E. Akatur**[1], **and S. H. Abedinpour**[2]

[1] *(Presenting author underlined) Department of Physics, Bilkent University, Bilkent, 06800 Ankara, Turkey*

[2] *Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran*

We consider a bilayer of dipolar particles in which the polarization of dipoles is perpendicular to the planes, in the antiparallel configuration. Using accurate static structure factor $S(q)$ data from hypernetted-chain and Fermi hypernetted-chain calculations, respectively for an isolated layer of dipolar bosons and dipolar fermions, we construct effective screened intralayer interactions. Adopting the random-phase approximation for interlayer interactions, we investigate the instability of these homogeneous bilayer systems towards the formation of density waves by studying the poles of the density-density response function. We have also studied the collective modes of these systems and find that the dispersion of their antisymmetric collective mode signals the emergence of the density wave instability as well.

Dimensional crossover in a strongly interacting ultracold atomic Fermi gas

Umberto Toniolo[1], **Brendan C. Mulkerin**[1], **Chris J. Vale**[1], **Xia-Ji Liu**[1], **and Hui Hu**[1]

[1] *Centre for Quantum and Optical Science, Swinburne University of Technology, Melbourne 3122, Australia*

In the work we present [1], we addressed the problem of how to treat the dimensional crossover, from 3D to 2D, in a ultracold strongly interacting atomic Fermi gas. The experimental research [2, 3] on this topic opened up the issue of finding a criterion to characterize whether a Fermi system can be considered confined in a proper two dimensional regime. Due to fluctuations, highly desruptive in the low-dimensional regimes, we proposed the interplay of hard-wall confinement, along the axial direction, partially treated with periodic boundary conditions, while the fluctuations are included using a beyond mean-field theory.

In the presence of strong interactions, we map out a dimensional crossover diagram in which we derived a new criterion to distinguish the dimensional regime and the position in the BCS-BEC crossover. The location of the maximum of the critical velocity, in the BCS-BEC crossover is used to establish both the dimensional and interacting regimes, in such a way the results are independent from the position of unitarity in 3D.

Moreover, we provided an experimentally viable method to probe the dimensional crossover diagram via the density dynamic structure factor, which characterizes the low-energy excitations of the system. Bragg spectroscopy is a viable technique to test our theoretical predictions, which are directly applicable to an interacting dimensional crossover Fermi gas realized by imposing a box trapping potential in the tight confinement direction [4].

[1] U. Toniolo, B. C. Mulkerin, C. J. Vale, X.-J. Liu, and H. Hu, ArXiv e-prints, 1701.08477 (2017).
[2] W. Ong, C. Cheng, I. Arakelyan, and J. E. Thomas, Phys. Rev. Lett. **114**, 110403 (2015).
[3] P. Dyke, K. Fenech, T. Peppler, M. G. Lingham, S. Hoinka, W. Zhang, S.-G. Peng, B. Mulkerin, H. Hu, X.-J. Liu, and C. J. Vale, Phys. Rev. A **93**, 011603(R) (2016).
[4] B. Mukherjee, Z. Yan, P. B. Patel, Z. Hadzibabic, T. Yefsah, J. Struck, and M. W. Zwierlein, Phys. Rev. Lett. **118**, 123401 (2017).