SuperFluctuations 2024

Fluctuations and Highly Nonlinear Phenomena In Superfluids and Superconductors

Sept. 16–18 2024

Salerno (Italy)

UNIVERSITÀ DEGLI STUDI DI SALERNO

Dipartimento di Fisica, Università di Salerno, Fisciano (Italy) (Sept.16)

Grand Hotel Salerno, Lungomare Tafuri, 1, Salerno (Italy) (Sept. 17–18)

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Topological Defects and Phase Transitions

(Plenary)

Monday 16 September
15:30 – 16:30

J. Michael Kosterlitz[1]

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This talk reviews some of the applications of topology and topological defects in phase transitions in two-dimensional systems for which Kosterlitz and Thouless split half the 2016 Physics Nobel Prize. The theoretical predictions and experimental verification in two-dimensional superfluids, superconductors and crystals provide remarkably convincing quantitative agreement with topological defect theories.

Lighting up superconductivity

Monday 16 September
17:00 – 17:30

Eugene Demler[1]

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We will discuss recent experiments in the pseudogap phase of the high Tc cuprate YBCO that have been interpreted as the light induced Meissner effect. A special feature of these materials is a bilayer structure with a large difference of Josephson couplings within the bilayers and between them. Motivated by this hierarchy of scales, we introduce a model that consists of bilayers of copper-oxygen planes with a local superconducting phase that persists up to the pseudo-gap temperature at equilibrium. Under pumping, the time evolution of the relative phase in the bilayers is described by a driven sine-Gordon equation. We will argue that the experimentally observed phenomena can be explained by a new type of dynamical instability in the sine-Gordon model triggered by the strong terahertz pump pulse. This interpretation suggests that these experiments reveal strong superconducting correlations in the pseudogap state but do not require photoinduced superconductivity.

Competition of Kondo scattering and Fano-Feshbach resonant pairing in artificial quantum heterostructures made by quantum design

Monday 16 September
17:30 – 18:00

Antonio Bianconi

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Recently, the quest for high-T_c superconductivity has evolved from the trial-and-error methodology to the growth of nanostructured artificial high-T_c superlattices (AHTS) with tailor-made superconducting functional properties by quantum design [1-4]. Superlattices are composed of nanoscale superconducting units of modulation doped Mott insulator La_2CuO_4 with thickness *L* intercalated by metallic overdoped $La_{1.55}Sr_{0.45}CuO_4$ and period d. Quantum design based on the multi-gap Bogoliubov theory including spin-orbit coupling (SOC). has been employed for prediction of the amplification of the critical temperature as a function of the conformational parameter L/d which gives origin to the superconducting dome by modulation of the pair transfer exchange interaction.

At the top of the superconducting dome, at the *magic* ratio L/d=2/3, the heterostructures are tuned at the Fano-Feshbach resonance and the normal phase exhibits the Planckian T-linear resistivity. Here, we report experimental evidence that the Kondo proximity effect competes with the Fano-Feshbach resonance suppressing T_c on both sides of the superconducting dome [5]. The Kondo proximity effect is expected in electrical resistance of AHTS nanoscale heterostructures following a Kondo universal scaling obtained by numerical renormalization group theory. We show the vanishing Kondo temperature T_K and Kondo scattering amplitude R_{0K} at L/d=2/3, while T_K and R_{0K} increase on the underdoped (L/d>2/3) and overdoped (L/d<2/3) side of the superconducting dome.

References

[1] Logvenov, G., Bonmassar, N., Christiani, G., Campi, G., Valletta, A., Bianconi, A. (2023). The superconducting dome in artificial high-Tc superlattices tuned at the Fano–Feshbach resonance by quantum design. *Condensed Matter*, *8*(3), 78
[2] Mazziotti, M. V., Valletta, A., Raimondi, R., Bianconi, A. (2021). Multigap superconductivity at an unconventional Lifshitz transition in a three-dimensional Rashba heterostructure at the atomic limit. *Physical Review B*, *103*(2), 024523.
[3] Mazziotti, M. V., Bianconi, A., Raimondi, R., Campi, G., Valletta, A. (2022). Spin–orbit coupling controlling the superconducting dome of artificial superlattices of quantum wells. *Journal of Applied Physics*, *132*(19).
[4] Valletta, A., Bianconi, A., Perali, A., Logvenov, G., & Campi, G. (2024). High-Tc superconducting dome in artificial heterostructures made of nanoscale quantum building blocks. *arXiv preprint arXiv:2407.19069*.
[5] Campi, G., Logvenov, G., Caprara, S., Valletta, A., & Bianconi, A. (2024). Kondo versus Fano in superconducting artificial high-Tc heterostructures. *arXiv preprint arXiv:2407.19068*.

Quantum devices based on Twisted Cuprate Heterostructures

Tuesday 17 September
09:00 – 09:30

V. Brosco,[1] A. Coppo, [1] L. Chirolli,[2] N. Poccia,[3,4] and U.Vool[5]

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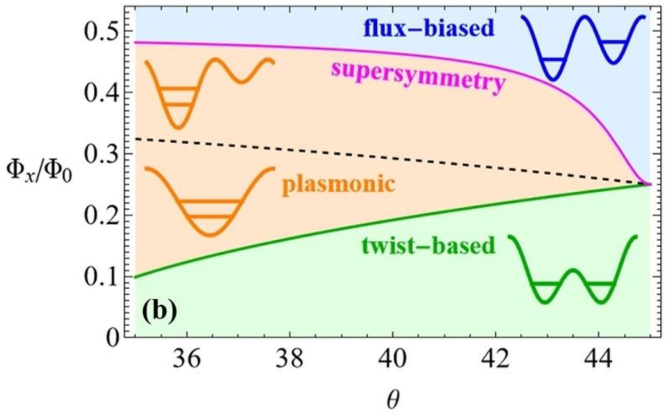
Recent advances in creating van der Waals heterostructures hosting ultrathin electronic states and in fabricating hybrid Josephson nanostructures have opened new research pathways for understanding and controlling the exotic electronic properties and functionalities emerging in these hybrid systems. In this talk, I will focus on the potential offered by integrating twisted cuprate van der Waals heterostructures into superconducting quantum devices.

I will demonstrate how the d-wave nature of the order parameter significantly impacts quantum coherence, potentially enabling the realization of a qubit with inherent topological protection against charge-noise-induced relaxation and quasiparticle-induced dissipation, dubbed the flowermon.

Next, I will present a novel quantum device comprising two twisted cuprate junctions integrated into a Superconducting Quantum Interference Device (SQUID) loop and threaded by an external magnetic flux. By adjusting the external flux and the twist angle, this device can be tuned into various regimes, each hosting distinct potential landscapes: a symmetric "twist-based" double-well potential, a "plasmonic" potential, and a "flux-biased" double-well potential, as illustrated in the figure.

The critical flux at which the circuit enters the flux-biased regime is a special point where the spectrum exhibits a supersymmetric structure. This point marks a change in the symmetry properties of the excited state and leads to significant modifications in the system's coupling to external noise fluctuations and, consequently, in the decoherence rates.



References
[1] V. Brosco, G. Serpico, V. Vinokur, N. Poccia and U. Vool, Phys. Rev. Lett. **132**, 017003 (2024).
[2] A. Coppo, L. Chirolli, N. Poccia, U. Vool and V. Brosco, arXiv:2405.03454 (2024).

Lifshitz transitions and Weyl semimetals from a topological superconductor with a current flow

Tuesday 17 September
09:30 – 10:00

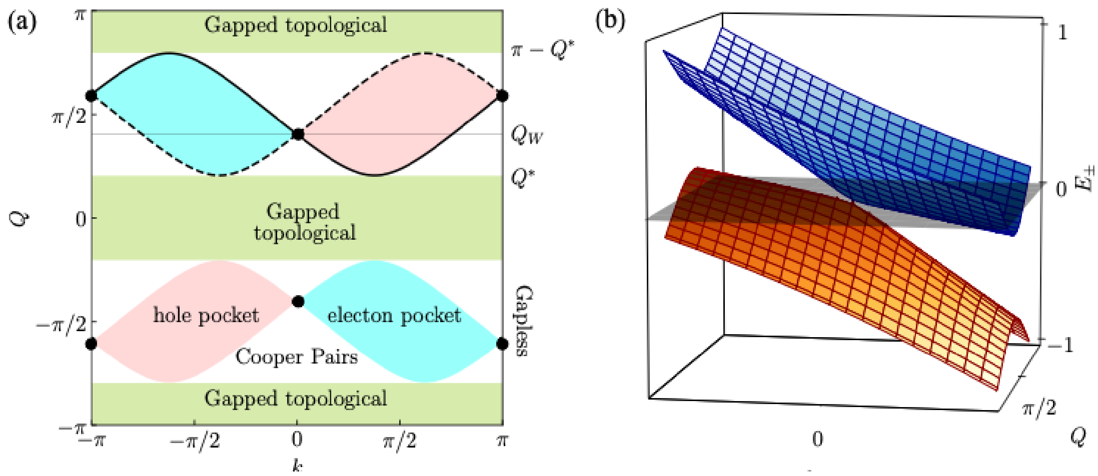
Fabian G. Medina Cuy[1], Francesco Buccheri[1] and Fabrizio Dolcini[1]

[1] Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, corso Duca degli Abruzzi 24, 10129 Torino (Italy)

A current flowing through a superconductor induces a spatial modulation in its superconducting order parameter, characterized by a wavevector Q related to the total momentum of a Cooper pair. We investigate this phenomenon in a p-wave topological superconductor, described by a one-dimensional Kitaev model. We demonstrate that, by treating Q as an extra synthetic dimension, the current carrying non-equilibrium steady state can be mapped into the ground state of a half-filled two-dimensional Weyl semimetal, whose Fermi surface exhibits Lifshitz transitions when varying the model parameters. Specifically, the transition from Type-I to Type-II Weyl phases correspond to the emergence of a gapless p-wave superconductor, where Cooper pairs coexist with unpaired electrons and holes. Such a transition is signalled by the appearance of a sharp cusp in the Q-dependence of the supercurrent, at a critical value Q^* that is robust to variations of the chemical potential μ. We determine the maximal current that the system can sustain in the topological phase, discuss possible implementations, and compare to the case of a conventional s-wave superconductor.

References

[1] F. Medina Cuy, F. Buccheri and F. Dolcini, ArXiv: 2404.18131 (2024)



(a) The Fermi surface of the 2D fermionic model associated to the Kitaev chain, where the superconducting phase modulation Q *is* treated as a synthetic dimension, consists of four Weyl nodes (black bullets), and of electron and hole pockets. Green areas denote the gapped topological phases of the 1D Kitaev chain, while in the other areas the Kitaev model exhibits a gapless superconducting state. (b) energy band in the vicinity of a Weyl node, showing that the associated 2D fermionic model is a Type-II Weyl Semimetal.

Topological Interlayer Superconductivity in a van der Waals Heterostructure

Tuesday 17 September
10:00 – 10:30

Jelena Klinovaja

Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

In my talk, I will show that when a honeycomb antiferromagnetic insulator (AFMI) is sandwiched between two transition metal dichalcogenide (TMD) monolayers in a commensurate way, magnons in the AFMI can mediate an interaction between electrons in the TMDs that gives rise to interlayer Cooper pairing. This interaction opens coexisting extended s-wave and chiral p-wave superconducting gaps in the energy spectrum of the coupled system, and the latter give rise to topological Majorana edge modes.

References

[1] Even Thingstad, Joel Hutchinson, Daniel Loss, Jelena Klinovaja, arXiv:2405.07927

Spin Geometric Phases and Josephson Diode Effect

Tuesday 17 September
11:00 – 11:30

Matthias Eschrig[1]

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Superconducting spintronics devices utilize Cooper pairs that carry a spin. A non-coplanar spin-texture in a magnetically active material leads to spin-geometric phases that directly imprint themselves on the phase of proximity-induced spinful Cooper pairs. This property of spin-geometric phases has the potential to lead to an entirely new branch in superconducting spintronics, introducing new types of control of superconducting devices. One prominent feature resulting from such an arrangement is the Josephson diode effect [1]. We study this effect for both ballistic and diffusive structures and show, that high efficiencies can be achieved in both cases. Important processes contributing are the crossed pair transmission process [1] in combination with equal-spin pair Josephson effects for the two spin bands of an itinerant ferromagnet, which are governed by spin-geometric phases [2, 3]. We present both numerical and analytical results for this effect and discuss the necessary conditions for its observation. In particular, we discuss symmetries of the Fourier coefficients in the current phase relation as function of the spin-geometric phases.

References

[1] R. Grein, M. Eschrig, G. Metalidis, and G. Schön, *Phys. Rev. Lett.* **102** (2009) 227005.
[2] M. Eschrig, *Reports on Progress in Physics* 78 (2015) 104501.
[3] M. Eschrig, in *Spintronics Handbook: Spin transport and magnetism* 2. ed. v. **1**, ch. 16 (2019) 635-682.

Quantum heat engines based on Josephson circuits

Tuesday 17 September
11:30 – 12:00

Francesco Giazotto[1]

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Thermoelectric effects in metals are typically small due to the nearly perfect particle-hole symmetry around their Fermi surface. Furthermore, thermo-phase effects and linear thermoelectricity in superconducting systems have been identified only when particle-hole symmetry is explicitly broken since thermoelectric effects were considered impossible in pristine superconductors.
Here, we experimentally demonstrate that superconducting tunnel junctions develop a very large bipolar thermoelectricity in the presence of a sizable thermal gradient thanks to spontaneous particle-hole symmetry breaking [1]. Our junctions show Seebeck coefficients of up to $\pm 300\ \mu V\ K^{-1}$, comparable with quantum dots and roughly 10^5 times larger than the value expected for normal metals at sub-kelvin temperatures [2]. Moreover, by integrating our junctions into a Josephson interferometer, we realize a bipolar thermoelectric Josephson engine generating phase-tunable electric powers of up to $\sim 140\ nW\ mm^{-2}$ [2,3]. Our device also implements the prototype for a persistent thermoelectric memory cell, written or erased by current injection. We expect that our findings will lead to applications in the field of superconducting quantum technologies [4,5].

We acknowledge funding from the EU's Horizon 2020 Research and Innovation Framework Programme under Grant No. 101057977 - SPECTRUM.

References

[1] G. Marchegiani, A. Braggio, and F. Giazotto, *Nonlinear thermoelectricity with electron-hole symmetric systems.* Phys. Rev. Lett. **124**, 106801 (2020).
[2] G. Germanese, F. Paolucci, G. Marchegiani, A. Braggio, and F. Giazotto, *Bipolar thermoelectric Josephson engine*, Nat. Nanotechnol. **17**, 1084 (2022).
[3] G. Germanese, F. Paolucci, G. Marchegiani, A. Braggio, and F. Giazotto, *Phase-control of bipolar thermoelectricity in Josephson tunnel junctions*, Phys. Rev. Applied **19**, 014074 (2023).
[4] F. Paolucci, G. Germanese, A. Braggio, and F. Giazotto, *A highly-sensitive broadband superconducting thermoelectric single-photon detector*, Appl. Phys. Lett. **122**, 173503 (2023).
[5] C. Guarcello, R. Citro, F. Giazotto, and A. Braggio, *Bipolar thermoelectrical SQUIPT (BTSQUIPT)*, Appl. Phys. Lett. **123**, 152601 (2023).

Coherent dynamics in mesoscopic circuits of cold atoms and superconducting networks

Tuesday 17 September
12:00 – 12:30

Luigi Amico

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Dipartimento di Fisica e Astronomia ’Ettore Majorana’, Via S. Sofia 64, 95123 Catania, Italy

Atomtronics is an emerging field that aims to manipulate ultracold atom moving in matter wave circuits for both fundamental studies in quantum science and technological applications. The field draws a lot from mesoscopic physics, the scope of which, in turn, can be widened by the specific capabilities of cold atoms. In this talk, I will provide two examples in which the interplay between superconducting and atomtronic circuits is particularly fruitful.

In the first part of the talk, I will consider driven atomic Josephson junctions realized by coupling two two-dimensional atomic clouds with a tunneling barrier. For such a system, I will show that the time-averaged particle imbalance across the junction features a step-like behavior that is the analog of Shapiro steps observed in driven superconducting Josephson junctions. In the second part of the talk, I will discuss how bright solitons originally studied for cold atoms trapped in one dimensional lattices allow to get relevant insights on the physical behavior of superconducting transmons chains.

References

[1] ‘Shapiro steps in driven atomic Josephson junctions’, V.P. Singh, J. Polo, L. Mathey, L. Amico
arXiv preprint arXiv:2307.08743

[2] ‘Soliton versus single-photon quantum dynamics in arrays of superconducting qubits’, B. Blain, G. Marchegiani, J. Polo, G. Catelani, L. Amico, Physical Review Research 5 (3), 033130

Cold numbers: Superconducting supercomputers, a case for delayed adoption due to the 'sailing-ship effect'?

Tuesday 17 September
12:30 – 13:00

Giovanni Filatrella[1], Nicola De Liso[2], Serena Arima[3]

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[2] Department of Law—Economics Division, University of Salento, Via per Monteroni snc, Lecce 73100, Italy
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Improvements experienced by incumbent "old" technologies when threatened by new ones, potentially supplanting them, are often addressed as the "sailing-ship effect." The latter phrase points to the eponymous case that consists of the 60-year or so technological battle between sail and steam in ships' propulsion during the 19th century, which led to unexpected large advancements in sail technology. Paradoxically, until today, the only work which addressed quantitatively that technological battle actually found a lack of evidence of the occurrence of the sailing-ship effect. In this paper, through fresh statistical analysis, we find instead confirmation of the existence of the effect in the original case. This finding contributes to the theoretical debate that explains technological persistence through mechanisms such as path dependence, cumulativeness, localized technical progress, competence and cognitive traps, the presence of complementary assets and tributary innovations, as well as institutional features. Superconducting supercomputers, as opposed to semiconductor based devices, will be discussed as a possible, and yet not certain, case of the sailing ship effect.

References

[1] N. De Liso, S. Arima, and G. Filatrella, "Is the "sailing-ship effect" misnamed? A statistical inquiry of the case sail vs steam in maritime transportation", *Industrial and corporate change* **32** (2023) 995.
[2] N. De Liso, G. Filatrella, D. Gagliardi, and C. Napoli, "Cold numbers: Superconducting supercomputers and presumptive anomaly", *Industrial and Corporate Change* **29**, (2020) 485–505.
[3] N. De Liso and G. Filatrella, *Economics of Innovation and New Technology* **17** (2008) 593.

Properties of the multifunctional 2DES at the $LaAlO_3/EuTiO_3/SrTiO_3$ interface

Tuesday 17 September
14:00 – 14:30

Yu Chen [1], Nand Kumar [2], Maria D'Antuono [2,1], Benoit Jouault [3], Marco Salluzzo [2] ,

Daniela Stornaiuolo [2,1]

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Two-dimensional electron systems (2DES) developing in SrTiO3-based heterostructures possess a wide range of properties which are largely tunable thanks to the system band structure and carrier density [1]. A joint experimental and theoretical approach is becoming essential to gain detailed understanding of these novel heterostructures showing exceptional properties, and as a guide for future design of materials for advanced applications.
Recently it was demonstrated that by introducing a thin layer of a magnetic oxide between $LaAlO_3$ and $SrTiO_3$, as in $LaAlO_3$ /$EuTiO_3$/ $SrTiO_3$ (LAO/ETO/STO) [001], a superconducting spin polarized 2DES can be engineered [2]. We present a combination of transport and spectroscopy measurements and DFT calculations used to resolve the nature of this 2DES and to understand the mechanisms leading to spin-polarization of its carriers [3]. In particular, we highlight the role of the carriers belonging to the Ti $3_{dxz,yz}$ states in establishing a ferromagnetic coupling, thanks to hybridization with specific Eu states.
We show also how the properties of the 2DES can be modulated by using electric field effect gating in combination with visible light irradiation [4]. A larger enhancement of the Ti $3_{dxz,yz}$ carriers mobility and, at the same time, an increase of the anomalous Hall resistance is obtained by light irradiation compared to back-gating. This effect could be related to light induced excitation of spin-polarized carriers at the interface, which distribute over the 2DES thickness well inside the STO.
Finally, we will discuss how our joint experimental and theoretical approach can be used to engineer a 2DES showing exotic quantum phenomena. We will show that the [111] LAO/ETO/STO interface, characterized simultaneously by ferromagnetic order, large Rashba spin-orbit coupling and hexagonal band warping [5], displays anomalous quantum corrections to the magneto-conductance explained by the emergence of a non-trivial Berry phase and competing weak anti-localization / weak localization back-scattering of Dirac-like fermions, mimicking the phenomenology of gapped topological insulators [6].

References

[1] D.V. Christensen et al. *Adv. Mater. Interfaces* **6**, 1900772 (2019)
[2] D. Stornaiuolo et al. *Nat. Mater.* **15**, 278–283 (2016).
[3] R Di Capua et al. *npj Quant. Mater*. **7**, 1–10 (2022)
[4] M.D'Antuono et al. *Scientific Reports*, 2023, 13.1: 10050
[5] Yu Chen et al., *ACS Applied Electronic Materials* 4, 3226 (2022)
[6] Y.Chen et al, *submitted*

The Shrinking Fermi liquid theory for strange metallicity in cuprates

Tuesday 17 September
14:30 – 15:00

Marco Grilli,[1,2] S. Caprara[1,2], C. Di Castro[1], G. Mirarchi[1], G. Seibold[3]

[1] Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
[2]ISC-CNR, Unità di Roma Sapienza, Roma, Italy.
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Anomalous metallic properties are often observed in the proximity of quantum critical points, with violation of the Fermi Liquid paradigm. We propose a scenario where, near a quantum critical point, dynamical fluctuations of the order parameter with *finite rather short correlation length* mediate a nearly isotropic scattering among the quasiparticles over the entire Fermi surface [1,2] leading to strange-metal behavior. If the damping of these nearly local fluctuations increases by decreasing the temperature, the Fermi liquid regime shrinks and the strange metallic behavior is extended to the lowest temperatures, possibly giving rise to a local quantum criticality [4]. This Shrinking Fermi liquid scenario accounts for both the linear-in-temperature resistivity and the seemingly divergent specific heat [2,3] observed, e.g., in high-temperature superconducting cuprates and some heavy-fermion metals. This scenario is investigated within a model of overdamped Holstein phonons [5] and it is shown that is has many similarities and some differences with respect to the Marginal Fermi Liquid scenario.
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References

[1]Götz Seibold, Riccardo Arpaia, Ying Ying Peng, Roberto Fumagalli, Lucio Braicovich, Carlo Di Castro, Marco Grilli, Giacomo Claudio Ghiringhelli, Sergio Caprara, Commun. Phys. **4**, 7 (2021)
[2]Sergio Caprara, Carlo Di Castro, Giovanni Mirarchi, Götz Seibold, Marco Grilli, Commun. Phys. **5**, 1-7 (2022).
[3]M Grilli, C Di Castro, G Mirarchi, G Seibold, S Caprara, Symmetry **15**, 569 (2023).
[4]Riccardo Arpaia, Leonardo Martinelli, M Moretti Sala, Sergio Caprara, Abhishek Nag, Nicholas B Brookes, Pietro Camisa, Qizhi Li, Qiang Gao, Xingjiang Zhou, Mirian Garcia-Fernandez, K-J Zhou, Enrico Schierle, Thilo Bauch, Ying Ying Peng, C Di Castro, M Grilli, Floriana Lombardi, Lucio Braicovich, Giacomo Ghiringhelli, Nat. Commun. **14**, 7198 (2023)
[5] G. Mirarchi, M. Grilli, G. Seibold, S. Caprara, Condensed Matter Physics **2024**, 9, 14

Gauge invariant quantum kinetic theory of multiband electron systems-applications to spintronics and orbitronics

Tuesday 17 September
15:00 – 15:30

R. Raimondi[1] and T. Valet[2]

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[2] Université Grenoble Alpes, CEA CNRS, Grenonle INP, Spintec

In a recent work [1], we have established the foundations of a U(1)×SU(N) gauge invariant quantum kinetic theory of general N-bands electron systems, driven by classical electromagnetic fields slowly varying in time and space on atomic scales. In this talk, and after a general introduction, we will first illustrate the power of this new framework on selected examples in spintronics. Namely, we will show how it enables straightforward concrete calculations shedding new lights on the subtle interplay between quantum geometry and disorder in modulating the spin hall effect [2–4] and the spin orbit torque effect [5, 6]. In a second part, we will turn our focus to orbitronics [7, 8], and discuss the concepts of orbital angular momentum [9] and orbital current [10–12] from a kinetic theory perspective.

References

[1] Valet, T.; Raimondi, R.EPL**2023**,143, 26004.
[2] Sinova, J.; Culcer, D.; Niu, Q.; Sinitsyn, N. A.; Jungwirth, T.; MacDonald, A. H.Phys. Rev. Lett.**2004**,92, 126603.
[3] Mishchenko, E. G.; Shytov, A. V.; Halperin, B. I.Phys. Rev. Lett.**2004**,93, 226602.
[4] Raimondi, R.; Gorini, C.; Schwab, P.; Dzierzawa, M.Phys. Rev. B**2006**,74, 035340.
[5] Manchon, A.; Zhang, S.Phys. Rev. B**2008**,78, 212405.
[6] Ado, I. A.; Tretiakov, O. A.; Titov, M.Phys. Rev. B**2017**,95, 094401.
[7]) Bernevig, B. A.; Hughes, T. L.; Zhang, S.-C.Phys. Rev. Lett.**2005**,95, 066601.
[8] Go, D.; Jo, D.; Kim, C.; Lee, H.-W.Phys. Rev. Lett.**2018**,121, 086602.
[9] Shi, J.; Vignale, G.; Xiao, D.; Niu, Q.Phys. Rev. Lett.**2007**,99, 197202.
[10] Bhowal, S.; Vignale, G.Phys. Rev. B**2021**,103, 195309.
[11] Cysne, T. P.; Bhowal, S.; Vignale, G.; Rappoport, T. G.Phys. Rev. B**2022**,105, 195421.
[12] Pezo, A.; Garcıa Ovalle, D.; Manchon, A.Phys. Rev. B**2022**,106, 104414.

High-orbital moment pairing states in spin-orbit free materials

Tuesday 17 September
15:30 – 16:00

Carmine Ortix[1], Maria Teresa Mercaldo[1], Mario Cuoco[2]

[1]Dipartimento di Fisica "E. R. Caianiello", Universita' di Salerno, Fisciano, Italy
[2] CNR-SPIN c/o Universita' di Salerno, Fisciano, Italy

In this talk, I will show that spin-singlet multiorbital superconducting states of materials with negligible spin-orbit coupling and unusually low crystalline symmetry content can host even-parity (s-wave) Cooper pairs with high orbital moment [1]. In particular, I will show that the lack of mirror and rotation symmetries makes pairing states with quintet orbital angular momentum symmetry allowed. I will then discuss two fingerprints of this type of pairing states: *i)* the possible presence of a vortex state with zero net magnetic flux made up of counterpropagating Cooper pairs with opposite orbital moments [2]; *ii)* nontrivial superconducting phase textures in momentum space with π-shifted domains and walls with anomalous phase winding. The pattern of the quintet pairing texture is shown to depend on the orientation of the orbital polarization and the strength of the mirror and/or rotation symmetry breaking terms. This momentum dependent phase makes Cooper pairs with net orbital component suited to design orbitronic Josephson effects.

References

[1] Maria Teresa Mercaldo, Carmine Ortix, Mario Cuoco, *Advanced Quantum Technologies* ***6*** (2023) 2300081
[2] Maria Teresa Mercaldo, Carmine Ortix, Francesco Giazotto, Mario Cuoco, *Phys. Rev. B* ***105*** (2022) L140507

Engineered Josephson diode effect in kinked Rashba nanochannels

Tuesday 17 September
16:30 – 16:50

Mattia Trama[1,2], Alfonso Maiellaro[2,3], Jacopo Settino[4,5], Claudio Guarcello[2,3], Francesco Romeo[2,3], and Roberta Citro[2,3]

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[5] INFN, Gruppo collegato di Cosenza, Italy

The superconducting diode effect [1], reminiscent of the unidirectional charge transport in semiconductor diodes, is characterized by a nonreciprocal, dissipationless flow of Cooper pairs. This phenomenon arises from the interplay between symmetry constraints and the inherent quantum behavior of superconductors. Here [2], we explore the geometric control of the diode effect in a kinked nanostrip Josephson junction based on a two-dimensional electron gas (2DEGs) with Rashba spin-orbit interaction. Our analysis reveals a rich phase diagram, showcasing a geometry and field-controlled diode effect. The phase diagram also reveals the presence of an anomalous Josephson effect related to the emergence of trivial zero-energy Andreev bound states, which can evolve into Majorana bound states. Our findings indicate that the exceptional synergy between geometric control of the diode effect and topological phases can be effectively leveraged to design and optimize superconducting devices with tailored transport properties.

References

[1] M. Nadeem, M. S. Fuhrer, and X. Wang, *Nat. Rew. Phys.* **5** (2023) 558.
[2] A. Maiellaro, M. Trama, J. Settino, C. Guarcello, F. Romeo and R. Citro, *arXiv:2405.17269* (2024).

Hunting fermion quadruplets: the case of magic-angle twisted bilayer graphene

Tuesday 17 September
16:50 – 17:10

Ilaria Maccari[1], Johan Carlström[2], Egor Babaev[3]

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Beyond the BCS fermion pairing paradigm, multi-component superconductors can host novel kinds of fermion condensates, where electrons condense in quadruplets rather than in pairs. These vestigial phases may appear both below and above the superconducting critical temperature as a result of the partial melting of the multiple broken symmetries of the ground state. Recently, the first experimental signatures of a non-superconducting fermion quadrupling condensate that spontaneously breaks time-reversal symmetry have been reported in a multi-band iron-based superconductor [1, 2]. From a theoretical standpoint, this is a beyond mean-field state whose onset is driven by the proliferation of topological phase excitations [3]. Alongside multi-band superconductors, also single-band superconductors with unconventional pairing may be good candidates to observe fermion quadrupling condensates. In a recent work [4], we studied a low-energy effective model proposed in [5] for magic-angle twisted-bilayer graphene. We found that, for all the model parameters investigated, a fluctuations-induced phase appears above the superconducting transition, where a condensate formed by four electrons breaks the time-reversal symmetry.

References

[1] Grinenko et al., *Nature Physics* 17, 1254–1259 (2021).
[2] I. Shipulin et al., *Nature Communications* 14, 6734 (2023).
[3] I. Maccari, E. Babaev, *Phys. Rev. B* 105 (21), 214520 (2022).
[4] I. Maccari, J. Carlström, E. Babaev, *Phys. Rev. B* 107 (6), 064501 (2023).
[5] D. V. Chichinadze, L.Classen, and A. V. Chubukov, *Phys. Rev. B* 101, 224513 (2020).

Dynamics of a Chester supersolid in dipolar condensates of interlayer excitons

Tuesday 17 September
17:10 – 17:30

Sara Conti[1], David Neilson[1], Andrey Chaves[2], Luis A. Peña Ardila[3], and Milorad Milosevic[1]

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Recent independent reports of signatures of superfluidity [1,2,3] of dipolar excitons have drawn enormous attention to excitonic bilayer semiconductor systems in which electrons and holes are separated and confined in different layers. In addition, we have predicted a transition to an incompressible exciton "Chester supersolid" in an experimentally accessible region of phase space [4].

Here we investigate the time-dependent dynamic supersolid condensate by solving the full Gross-Pitaevskii equation for the 2D dipolar excitonic system. In this system, the interaction between the excitons is purely repulsive long-range dipole-dipole. This is in marked contrast with the ultracold dipolar gases [5], where the dynamic is also driven by an effective attractive interaction. The Gross-Pitaevskii equation admits solutions dependent on the experimental parameters, electron-hole layer separation and density. We establish that the Gross-Pitaevskii equation leads to a ground state lattice structure, with occupancy of the lattice sites equal to one, in the region of phase space where we predict the Chester supersolid.

We further investigate the formation of vortices, which can be used to experimentally establish unequivocally the appearance of Bose-Einstein Condensation in these exciton systems [6] and the transition from superfluid to supersolid [7]. In our system, the exciton vortex properties can be experimentally tuned both by changing the layer separation and by tuning the density, exploiting the dependence of the vortex core on the relative strength of the exciton dipole moment relative to its kinetic energy. We find that, when the layer separation is increased and we enter the region of phase space occupied by the supersolid, an interesting maximum in the density redistribution appears around the edge of each vortex. This is associated to the roton minimum mixing with the ground-state and can be seen as precursor of crystallization [8].

References

[1] G.W. Burg, N. Prasad, K. Kim, T. Taniguchi, K. Watanabe, et al., *Phys. Rev. Lett.* **120**, 177702 (2018).
[2] L. Ma, P.X. Nguyen, Z. Wang, Y. Zeng, K. Watanabe, et al., *Nature* **598**, 585-589 (2021).
[3] P. X. Nguyen, L. Ma, R. Chaturvedi, K. Watanabe, T. Taniguchi, et al., arXiv: 2309.14940 (2023).
[4] S. Conti, A. Perali, A. R. Hamilton, M. V. Milošević, F. M. Peeters, & D. Neilson, *Phys. Rev. Lett.* **130**, 057001 (2023).
[5] B. C. Mulkerin, R.M.W. van Bijnen, D.H.J. O'Dell, A. M. Martin, & N.G. Parker, *Phys. Rev. Lett.* **111**, 170402 (2013)
[6] F. Ancilotto, M. Barranco, M. Pi, and L. Reatto, *Phys. Rev. A*, 103, 033314 (2021).
[7] M. Zwierlein, J. Abo-Shaeer, A. Schirotzek, A. Schirotzek, C. H. Schunck & W. Ketterle, *Nature* **435**, 1047–1051 (2005).
[8]S. Yi and H. Pu, *Phys. Rev. A* **73**, 061602(R) (2006)

Quantum sensing of dark matter with a phase resolved haloscope

Tuesday 17 September
17:30 – 17:50

A. Théry[1], C. Fruy[1], B. Hue[1], L. Jarjat[1], J. Craquelin[1], W. Legrand[1], M.R. Delbecq[1,2], A. Cottet[1,2], T. Kontos[1,2]

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There is a general consensus that only a small fraction of the matter and energy in the universe has been detected (about 5%), with the rest being dark matter (about 27%) and dark energy (about 68%). Understanding the nature and properties of these objects is one of the greatest challenges in physics. Dark matter is generally thought to consist of particles that "flood" galactic halos and thus the Milky Way. It can therefore, in principle, be detected in laboratory experiments.

One possible candidate for dark matter are hypothetical particles that do not belong to the Standard Model, called axions. They were first introduced to solve the strong CP problem in quantum chromodynamics and explain the absence of an electric dipole moment for the neutron [1]. They are also credible candidates for dark matter in the Universe. Under a high DC magnetic field, an axion can decay into a photon of energy corresponding to the axion mass. Three-dimensional cavities in high magnetic fields can therefore serve as axion detectors, as first proposed by P. Sikivie in 1983 [2]. These devices, known as cavity haloscopes, are however limited to a narrow range of accessible frequencies as opposed to the wide range of possible axion masses. Their sensitivity is also bound by the standard quantum limit, which has slowed down the axion dark matter sensing efforts so far.

Our haloscope is different in concept from all the existing platform, as it combines a superconducting circuit, an antiferromagnetic crystal and a microwave cavity. It aims to detect the axion signal by measuring a phase shift of the microwave signal, which can outcast the standard quantum limit. Furthermore, the antiferromagnetic crystal provides a frequency tunability of the detector, enabling in principle a large mass range.

In my talk, I will first present our results concerning the physics of the superconducting circuit [3], the antiferromagnetic and the cavity modes. Finally, I will focus on axion quantum sensing. I will show in particular that our hybrid magnon-superconducting circuit-cavity platform is a scanning phase haloscope which should enable a substantial speed-up in the axion dark matter search.

References

[1] R. D. Peccei and H. R. Quinn, *CP conservation in the presence of pseudoparticles*, Phys. Rev. Lett. **38**, 1440 (1977).
[2] P. Sikivie, *Experimental tests of the "invisible" axion*, Phys. Rev. Lett. **51**, 1415 (1983).
[3] A. Théry et al., *Observation of quantum oscillations in the extreme weak anharmonic limit*, Phys. Rev. B. **109**, 064505 (2024).

Exploring superfluidity in flat-band Bose systems through quantum geometry

Tuesday 17 September
17:50 – 18:10

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Quantum geometry provides a framework for studying condensed matter systems by examining the properties of wave functions in momentum space. It is characterized by a tensor, with its real part dictating geometrical properties through the Fubini-Study quantum metric and its imaginary part determining the topology via the Berry curvature [1].
In this talk, we discuss the role of quantum geometry in the phenomenology of flat band bosonic systems, where kinetic effects are suppressed while interactions are enhanced. Initially, we discuss the properties of weakly interacting Bose-Einstein condensates using the multiband Bogoliubov theory. Our findings reveal that the speed of sound and the excitation fraction are dictated by the underlying *quantum distance* of the condensate state. Specifically, a condensate quantum distance involves generalizations of the quantum metric, which are independent on the orbital positions and reduce to the usual Fubini-Study metric in special cases [2-3]. Interestingly, we highlight the role of quantum fluctuations in inducing a finite superfluidity in flat band models. With exact diagonalization techniques, we show that the superfluidity in one-dimensional Bose-Hubbard models is also governed by a many-body version of the quantum metric. This approach provides a more accurate representation of the superfluid characteristics in these systems beyond Bogoliubov theory, with the many-body quantum metric determining the upper bound of the Drude weight [4].
Our results highlight the broad implications of the quantum geometric effects in enhancing the role of interactions, especially in weakly coupled systems, such as ultracold atoms as well as photonic and polaritonic BECs. We suggest potential applications in designing quantum technologies relying on quantum geometry effects, ranging from ultracold gases to circuit-QED and non-Hermitian plasmonic lattices of metallic nanoparticles [5].

References

[1] Resta, *The European Physical Journal B* **79**, 121 (2011)
[2] Julku, Bruun & Törmä, *Phys. Rev. Lett.* **127**, 170404 (2021)
[3] Julku, Salerno & Törmä, *Low Temp. Phys.* **40**, 701 (2023)
[4] Salerno, Ozawa & Törmä, *Phys. Rev. B* **108**, L140503 (2023)
[5] Pyykkönen, Salerno, Kähärä & Törmä, *Phys. Rev. Research* **5**, 043259 (2023)

Transport signatures of filamentary superconductivity in low dimensional systems

Tuesday 17 September
18:10 – 18:30

Giulia Venditti[1], Ilaria Maccari[2], Marco Grilli[3], Jose Lorenzana[3,4], and Sergio Caprara[3]

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In several classes of low-dimensional superconducting (SC) systems, there is increasing evidence that the strongly inhomogeneous nature of the electronic condensate appears as a filamentary SC pattern. Here, the SC condensate shows a substantially different phenomenology from what is expected in a purely 2D system [1,2], where a Berezinskii-Kosterlitz-Thouless (BKT) transition is expected. While the microscopic mechanism generating phase separation depends on the specific system under investigation, macroscopic properties are generally related to the possible filamentary geometry.
Specifically, transport features are closely linked to the geometry of the condensate, where the zero-resistance state can be reached only when a percolating SC path forms. In this scenario, superfluid density and stiffness can become highly inequivalent quantities. By mapping the problem into a random impedance network (RIN) model, we show how the superfluid response of the system non-trivially depends on its microscopic and macroscopic characteristics. Moreover, different doping regimes can be understood in terms of an intrinsically less or more robust filamentary SC condensate [2]. The RIN model is a great yet simple tool to infer the microscopic structure of the SC cluster and reveal signatures of filamentary superconductivity. However, it does not address the causes behind such filamentarity.
Among others, one possible phase separation mechanism is the competition of superconductivity with another phase. Considering the case of cuprates, we argue that there is a special doping point, where the condensation of holes into a charge-ordered and into a superconducting phase are degenerate in energy but with an energy barrier in between [3]. By means of a phenomenological 2d XXZ model, we show filamentary superconductivity emerging as domain walls between different charge-ordered realizations. Contextually, BKT signatures get smeared out until they disappear. Once we assume weak interlayer couplings, the resulting phase diagram of the three-dimensional system is in good agreement with the typical cuprates phase diagrams.

References

[1] G. Venditti, J. Biscaras, S. Hurand, N. Bergeal, J. Lesueur, A. Dogra, R. C. Budhani, Mintu Mondal, John Jesudasan, Pratap Raychaudhuri, S. Caprara, and L. Benfatto, *Phys. Rev. B* **100 (2019)** 064506.
[2] G. Venditti, I. Maccari, A. Jouan, G. Singh, R. C. Budhani, C. Feuillet-Palma, J. Lesueur, N. Bergeal, S. Caprara, M. Grilli, *SciPost Phys.* **15 (2023)** 239.
[3] G. Venditti, I. Maccari, J. Lorenzana, and S. Caprara, *SciPost Phys.* **15 (2023)** 230.

Non-Abelian Thouless pumping in a two-leg ladder

Tuesday 17 September
18:30 – 18:50

Carlo Danieli[1], Valentina Brosco[1], Laura Pilozzi[1], and Roberta Citro[2]

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Non-Abelian Thouless pumping holds promise for technological applications such as quantum computing and quantum logic. We discuss a two-leg ladder model featuring doubly-degenerate bands. We demonstrate that adiabatic manipulation of the lattice parameters results in non-Abelian Thouless pumping, which induces both the displacement of an initially localized state and a geometric unitary transformation within the degenerate subspace. By carefully de- signing the pumping cycle, we achieve adiabatic and topological transport of bond states. This proposed non-Abelian pumping scheme can be implemented using a cold atom system with quantum gas microscopy.

Dynamical Projective Operatorial Approach (DPOA) for Pump-Probe Setups in the Ultrafast Regime

Wednesday 18 September
09:30 – 10:00

Amir Eskandari-asl[1] and Adolfo Avella[1,2,3]

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Recent experimental advancements in ultrafast pump-probe setups drive a growing need for efficient and insightful theoretical methods. This study will delve into the internals of our newly developed method, the Dynamical Projective Operatorial Approach (DPOA) [1-3]. DPOA stands out as a highly efficient model-Hamiltonian method capable of calculating a wide range of single/multi-time single/multi-particle properties, such as excitation populations, out-of-equilibrium Green's functions, TR-ARPES signals [2], and various response functions. When dealing with transient optical properties, utilizing the DPOA formulation and capitalizing on the weak intensity of the probe pulse, we efficiently compute the linear response of the pumped system to a generic probe pulse, significantly accelerating calculations [3]. Alongside the theoretical framework, we present noteworthy results that experimentalists can utilize to establish connections between observed effects and their underlying physical phenomena.

References

[1] G. Inzani, L. Adamska, A. Eskandari-asl, N. D. Palo, G. L. Dolso, B. Moio, L. J. D'Onofrio, A. Lamperti, A. Molle, R. Borrego-Varillas, M. Nisoli, S. Pittalis, C. A. Rozzi, A. Avella, and M. Lucchini, *Nature Photonics* **17** (2023) 1059.
[2] A. Eskandari-asl and A. Avella, Dynamical Projective Operatorial Approach (DPOA) for Out-Of-Equilibrium Systems and its Application to TR-ARPES, arXiv:2307.01244 (2023).
[3] A. Eskandari-asl and A. Avella, Generalized Linear Response Theory for Pumped Systems and its Application to Transient Optical Properties within DPOA, arXiv:2404.10768 (2024).

Effects of quantum depletion and gradient corrections on the critical atom number of dipolar droplets

Wednesday 18 September
10:00 – 10:30

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The first experimental realization of quantum droplets in dipolar condensates [1] has highlighted the importance of quantum fluctuations [2,3], which were later shown to be the main source of system's stability against the dipolar collapse. The droplets were predicted and shown to be self-bound beyond the critical atom number even without the trap. However, there is a systematic difference in theoretical estimates of the critical atom number and experimental results [4]. Here we use an approach based on the extended Gross-Pitaevskii equation, which includes quantum depletion and beyond-LDA gradient corrections, to numerically and variationally study their effects on the critical atom number.

References

[1] H. Kadau et al., *Nature* **530** (2016) 194.
[2] A. R. P. Lima and A. Pelster, *Phys. Rev. A* **84** (2011) 041604(R).
[3] A. R. P. Lima and A. Pelster, *Phys. Rev. A* **86** (2012) 063609.
[4] F. Böttcher et al., *Phys. Rev. Research* **1** (2019) 033088.

Berezinskii-Kosterlitz-Thouless transition in a two-dimensional binary Bose mixture

Wednesday 18 September
11:00 – 11:30

Koichiro Furutani[1,2]

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We theoretically investigate the Berezinskii-Kosterlitz-Thouless (BKT) phase transition in a two-dimensional binary Bose mixture in the miscible state. The BKT transition is a topological phase transition resulting from the vortex excitations. In contrast to a single-component Bose superfluid, a multicomponent superfluid can host multiple kinds of vortex excitations and fractional circulation can appear. Consequently, the BKT physics exhibits a rich variety of superfluid properties. We perform the RG analysis of the superfluid density and the BKT transition temperature in a miscible two-component Bose superfluid [1]. With the analytic approach, we find the enhancement of the BKT transition temperature with a strong Rabi coupling and its nonmonotonic behavior with respect to the two-body intercomponent coupling. We also point out qualitatively distinct behavior of the sound velocities at low temperatures from the single-component case, which can be tested experimentally. Moreover, we clarify the change of universal jumps by a finite population imbalance with the RG approach. In this imbalanced case, the superfluid phase stiffness undergoes twice universal jumps due to the two different BKT transition temperatures, which is consistent with a Monte Carlo simulation [2]. The modification of universal jumps originates from the contribution of the multiple kinds of vortex excitations in a binary Bose mixture.

References

[1] K. Furutani, A. Perali, and L. Salasnich, *Phys. Rev. A* **107** (2023) L041302.
[2] M. Kobayashi, M. Eto, and M. Nitta, *Phys. Rev. Lett* **123** (2019) 075303.

Simulating the dynamics of open quantum systems via the time dependent Variational Monte Carlo method

Wednesday 18 September
11:30 – 12:00

Jacopo D'Alberto[1], Christian Apostoli[1], Gianluca Bertaina[2] and Davide Emilio Galli[1]

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The interest in quantum technologies has surged dramatically in recent years, particularly in the quest to achieve the supremacy of quantum simulators over classical counterparts. One of the foremost challenges in this domain is the effective understanding and manipulation of open quantum systems, which could be pivotal for the development of advanced quantum technologies. Although several approximate methods have been developed to simulate the dynamics of open quantum systems [1], their applications have generally been limited to small-sized systems. Our novel approach leverages the time-dependent Variational Monte Carlo (TD-VMC) method, as utilized also in a prior work [2]. Our method exploits the unravelling of master equations to generate a set of quantum trajectories evolving according to Stochastic Schrödinger Equations (SSE). By solving for multiple independent trajectories, we can reconstruct time-dependent observables that correspond to those derived from the master equations. We demonstrate the application of this method to dissipative quantum many-body models, utilizing various variational ansätze. These range from Jastrow wavefunctions to more sophisticated Neural Networks Quantum States (NNQS) [3].

References

[1] H. Weimer, A. Kshetrimayum and R. Orús, Rev. Mod. Phys. 93, 015008 (2021).
[2] M. J. Hartmann and G. Carleo, Phys. Rev. Lett. 122, 250502 (2019).
[3] G. Carleo and M. Troyer, Science 355, 602 (2017).

Combining deep learning with quantum Monte Carlo algorithms and with density functional theory

Wednesday 18 September
12:00 – 12:30

[*1,2]Luca Brodoloni, [1,2,3]Emanuele Costa, [1,2]Simone Cantori, [1,2]Giuseppe Scriva, [4,5]Rosario Fazio, [1,2]Sebastiano Pilati

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Deep learning techniques pave the way to novel strategies to tackle hard computational tasks in quantum many-body physics. In this talk, I will discuss two examples, mostly addressing models of disordered quantum spins. In the first example, artificial neural networks are used to boost projection quantum Monte Carlo simulations. This allows us simulating the ground-state of a prototypical short-range quantum spin glass, namely, the two-dimensional Edwards-Anderson model with transverse field. The replica spin-overlap is determined to analyze the spin-glass quantum phase transition and the nature of the spin-glass phase. I will possibly discuss the perspective of implementing spin-glass models in Rydberg atoms arrays.
In the second example, neural networks are trained to learn from data accurate energy functionals for density functional theory [1,2,3]. As we numerically demonstrate, exploiting suitably designed scalable neural networks allows one to accurately simulate disordered quantum systems at an affordable computational cost. We also exploit so-called variational autoencoder networks to learn a compressed but regular representation of the quantum system. This allows us solving density functional theory avoiding the instabilities encountered with other deep learning based energy functionals.

References
[1] E. Costa, G. Scriva, S. Pilati, *arXiv*:2403.09788 (2024).
[2] E. Costa, R. Fazio, S. Pilati, *Phys. Rev. B* **108** (2023) 125113.
[3] E. Costa, G. Scriva, R. Fazio, S. Pilati, *Phys. Rev. E* 106 (2022) 045309.

Bose and Fermi Polarons in Atom- Ion Hybrid Systems

Wednesday 18 September
12:30 – 13:00

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https://cqm.unicam.it

Charged quasiparticles dressed by the low excitations of an electron gas constitute one of the fundamental pillars for understanding quantum many-body effects in some materials. Quantum simulation of quasiparticles arising from atom-ion hybrid systems may shed light on solid-state uncharted regimes. Here, we will discuss ionic polarons created as a result of charged dopants interacting with a Bose-Einstein condensate [1,2] and a polarized Fermi gas [3]. Here, we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium and an ideal Fermi gas with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state in the bosonic case; in contrast, a molecular state appears in the Fermi case. We unravel their vastly different polaronic properties compared to neutral quantum impurities using quantum Monte Carlo simulations. Contrary to the case of neutral impurities, ionic polarons can bind many excitations, forming a nontrivial interplay between few and many-body physics, radically changing the ground-state properties of the polaron.

[1] Astrakharchik, G.E., LAPA, Schmidt, R. *et al.* Ionic polaron in a Bose-Einstein condensate. *Commun Phys* **4**, 94 (2021).
[2]. Astrakharchik, G.E., LAPA., Jachymski, K. *et al.* Many-body bound states and induced interactions of charged impurities in a bosonic bath. *Nat Commun* **14**, 1647 (2023).
[3] R.Pessoa, S. A Vitiello, LAPA. Fermi polaron in atom-ion hybrid systems. ArXiv:2401.05324 (2024).

Superfluidity meets the solid state- towards frictionless molecular transport in narrow nanotubes

Wednesday 18 September
14:00 – 14:30

Alberto Ambrosetti[1], Pier Luigi Silvestrelli[1], and Luca Salasnich[1,2]

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Tribological effects are consistently addressed by semi-classical theories that associate corrugated interface potentials to the rise of friction forces and energy dissipation. This seemingly incontrovertible picture is challenged by experimental observation of exceptionally high permeabilities for water flow in narrow carbon nanotubes (CNT's), that exceed semi-classical estimates by 2-4 orders of magnitude -- suggesting virtually vanishing friction. Here we introduce [1,2] a formally exact, fully quantum mechanical theory for the wave-like flow of small particles through narrow nanotubes, explicitly accounting for realistic interface potentials V_{eff}, computed from first principles. We find that frictionless particle flow (denominated as *superflow*) can surprisingly take place even in the presence of non-negligible corrugation in V_{eff}, below a critical velocity v_c. The critical velocity is renormalized by V_{eff} and by the particle mass. Moreover, partial *superflow* (quantum superposition of *superflowing* and normal state) can persist for velocities exceeding v_c by two orders of magnitude, implying quantum-mechanical friction suppression, and gradual transition to the semi-classical regime.

References

[1] A. Ambrosetti, P.L. Silvestrelli, L. Salasnich, *Phys Rev. Lett.* **131** (2023) 206301.
[2] A. Ambrosetti, L. Salasnich, (2024) submitted.

Quantum droplets in a bosonic mixture of ^{41}K and ^{87}Rb

Wednesday 18 September
14:30 – 15:00

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Liquid-like quantum droplets are a novel state of matter forming in degenerate ultracold gases with competing interactions. Such states may form in two-component bosonic mixtures due to the competition between the intercomponent attraction and repulsive quantum fluctuations [1]. Binary quantum droplets have been realized in both homonuclear [2,3] and heteronuclear mixtures [4,5]. In the latter case, the droplet lifetime, which is limited by three-body losses, is prolonged enabling the study of phenomena occurring on a time scale of tens of milliseconds.
In this talk, I will illustrate our recent experimental results on the formation and dynamics of ^{41}K-^{87}Rb quantum droplets. Specifically, I will focus on our recent observation of multiple droplet formation through dynamical instability. A single droplet confined in a tight optical waveguide, subject to a contraction-elongation mode, expands up to a critical length then it breaks up into two or more smaller droplets. The number of formed droplets increases both by increasing the atom number and by decreasing the interspecies attraction. These scalings are consistent with capillary instability, which causes the breakup of a classic [7], or quantum liquid filament [8] into droplets because of the surface tension. Our results prove the liquid behavior of ^{41}K-^{87}Rb droplets and open new possibilities to explore the dynamics of these quantum liquids. Finally, I will discuss future perspectives of our experiment, which may include the study of non-trivial superfluid structures, like rings and shells, as well as exotic vortex states and rotating droplets.

References

[1] D. Petrov, *Phys. Rev. Lett.* **115** (2015) 155302.
[2] C. R. Cabrera et al., *Science* **359** (2018) 301.
[3] G. Semeghini et al., Phys. Rev. Lett. **120** (2018) 235301.
[4] C. D'Errico et al., *Phys. Rev. Res*. **115** (2019) 033155.
[5] A. Burchianti et al., *Condens. Matter* **5** (2020) 21.
[6] Z. Guo et al., Phys. *Rev. Res.* **3** (2021) 033247.
[7] F. R. S. Lord Rayleigh, *Proc. London Math. Soc.* **57** (1879) s1-11.
[8] F. Ancilotto et al., *Phys. Rev. A* **107** (2023) 063312.

Beyond universality in Fermi and Bose gases

Wednesday 18 September
15:00 – 15:30

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Itinerant ferromagnetism in dilute Fermi gases is predicted to emerge at values of the gas parameter where second-order perturbation theory is not accurate enough to properly describe the system. We have revisited perturbation theory for SU(N) fermions and derived its generalization up to third order both in terms of the gas parameter and the polarization. Our results agree satisfactorily with quantum Monte Carlo results for hard-sphere and soft-sphere potentials for S = 1/2. Although the nature of the phase transition depends on the interaction potential, we find that for a hard-sphere potential a phase transition is guaranteed to occur. While for S= 1/2 we observe a quasi-continuous transition, for spins 3/2 and 5/2, a first-order phase transition is found. For larger spins, a double transition (combination of continuous and discontinuous) occurs. The critical density reduces drastically when the spin increases, making the phase transition more accessible to experiments with ultracold dilute Fermi gases. Estimations for Fermi gases of Yb and Sr with spin 5/2 and 9/2, respectively, are reported. In the case of dilute bosons, the non-universal terms are not analytically known. We have carried out a rather extensive study of the equation of state of a Bose gas beyond the universal terms using quantum Monte Carlo methods and analyzed its dependence on the effective range and p-wave scattering length.

Bose mixtures at finite temperature: magnetism and condensation phenomena

Wednesday 18 September
15:30 – 16:00

S. Giorgini

Pitaevskii BEC Center CNR-INO, and Dipartimento di Fisica,

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I will review recent works on the study of both repulsive and attractive Bose mixtures at finite temperature using exact path-integral quantum Monte-Carlo numerical methods. Repulsive mixtures in the quantum degenerate regime undergo a first-order ferromagnetic transition as a function of the interspecies coupling constant. The magnetic behavior close to the point of phase separation is found to contradict predictions based on mean-field and perturbative theories. Attractive mixtures are investigated focusing on the regime of interspecies interactions where the ground state is in a self-bound liquid phase, stabilized by beyond mean-field effects. Calculations of the isothermal curves in the pressure vs density plane are reported for different values of the attraction strength and the extent of the coexistence region between liquid and vapor is established. A similar behavior is observed both in 3D and 2D geometries. In particular, the transition to the superfluid state occurs in a discontinuous way as the density jumps from the gas to the liquid phase. Furthermore, in 3D, the line of first-order transition terminates at a tricritical point and in 2D a relevant role in the gas-liquid transition is played by the quantum scale anomaly. The experimental relevance of these findings is also discussed.

References

[1] Phase separation in binary Bose mixtures at finite temperature, G. Spada, L. Parisi, G. Pascual, N. G. Parker, T. P. Billam, S. Pilati, J. Boronat and S. Giorgini, SciPost Phys. **15**, 171 (2023).

[2] Attractive solution of binary Bose mixtures: liquid-vapour coexistence and critical point, G. Spada, S. Pilati and S. Giorgini, Phys. Rev. Lett. **131**, 173404 (2023).

[3] Quantum droplets in two-dimensional Bose mixtures at finite temperature, G. Spada, S. Pilati and S. Giorgini, preprint, arXiv:2405.09368.

Symmetry oscillations in strongly interacting one-dimensional mixtures

Wednesday 18 September
16:30 – 17:00

S. Musolino[1, 2], M. Albert[2, 3], A. Minguzzi[1] and P. Vignolo[2, 3]

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Multi-component quantum mixtures in one dimension can be characterized by their symmetry under particle exchange. For a strongly-interacting Bose-Bose mixture, we show that the time evolution of the momentum distribution from an initially symmetry-mixed state is quasi-constant for a *SU(2)* symmetry conserving Hamiltonian, while it displays large oscillations in time for the symmetry-breaking case where inter- and intra-species interactions are different.
Using the property that the momentum distribution operator at strong interactions commutes with the class-sum operator, the latter acting as a symmetry witness, we show that the momentum distribution oscillations correspond to symmetry oscillations, with a mechanism analog to neutrino flavour oscillations.

References

[1] S. Musolino, M. Albert, A. Minguzzi and P. Vignolo, arXiv:2407.00194 (2024)
[2] J. Xhie, K. Sattler, M. Ge, N. Venkateswaran, *Phys. Rev. B* **47** (1993) 15835.

Dynamical Projective Operatorial Approach (DPOA) for Pump-Probe Setups in the Ultrafast Regime

(Poster)
Monday 16 September
18:00 – 19:30

Amir Eskandari-asl[1] and Adolfo Avella[1,2,3]

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Recent experimental advancements in ultrafast pump-probe setups drive a growing need for efficient and insightful theoretical methods. This study will delve into the internals of our newly developed method, the Dynamical Projective Operatorial Approach (DPOA) [1-3]. DPOA stands out as a highly efficient model-Hamiltonian method capable of calculating a wide range of single/multi-time single/multi-particle properties, such as excitation populations, out-of-equilibrium Green's functions, TR-ARPES signals [2], and various response functions. When dealing with transient optical properties, utilizing the DPOA formulation and capitalizing on the weak intensity of the probe pulse, we efficiently compute the linear response of the pumped system to a generic probe pulse, significantly accelerating calculations [3]. Alongside the theoretical framework, we present noteworthy results that experimentalists can utilize to establish connections between observed effects and their underlying physical phenomena.

References

[1] G. Inzani, L. Adamska, A. Eskandari-asl, N. D. Palo, G. L. Dolso, B. Moio, L. J. D'Onofrio, A. Lamperti, A. Molle, R. Borrego-Varillas, M. Nisoli, S. Pittalis, C. A. Rozzi, A. Avella, and M. Lucchini, *Nature Photonics* **17** (2023) 1059.
[2] A. Eskandari-asl and A. Avella, Dynamical Projective Operatorial Approach (DPOA) for Out-Of-Equilibrium Systems and its Application to TR-ARPES, arXiv:2307.01244 (2023).
[3] A. Eskandari-asl and A. Avella, Generalized Linear Response Theory for Pumped Systems and its Application to Transient Optical Properties within DPOA, arXiv:2404.10768 (2024).

Andreev spin-noise detector

(Poster)
Monday 16 September
18:00 – 19:30

Roberto Capecelatro[1], Valentina Brosco[2,3], Gabriele Campagnano[4] and Procolo Lucignano[1]

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We investigate the possibility to employ magnetic Josephson junctions as spin-noise detectors. Spin noise spectroscopy plays a fundamental role for detecting electron-spin dynamics in semiconductor heterostructures as well as in spin glasses and superconductors, both with optical techniques and by the means of SQUID-based magnetometry. We propose to probe the microscopic properties of spin noise sources from Josephson current noise measurements and from the knowledge of the detector equilibrium transport properties. To illustrate our idea, we consider a system consisting of a quantum dot coupled to superconducting leads in the presence of an external magnetic field. We present a detailed study of the microscopic mechanisms underlying the current noise response in this Josephson device with the aim of exploiting the magnetic field dependence of Andreev tunneling to detect spin noise. Under appropriate assumptions, we relate the noise in the Josephson current to magnetization noise. At the magnetic field driven $0-\pi$ transition the junction sensitivity as magnetic noise detector is strongly enhanced and it diverges in the zero-temperature limit. The fingerprint of this phenomenon is the presence of jump discontinuities in the junction current phase relation. We show that, in the optimal working conditions, our detector results much more sensitive to spin rather charge noise, and it is also immune to the detrimental effect of quasiparticles on magnetic noise amplification. Temperature behavior of this magnetic quantum-dot junction promises even improved performances when operating in the low temperature limit.

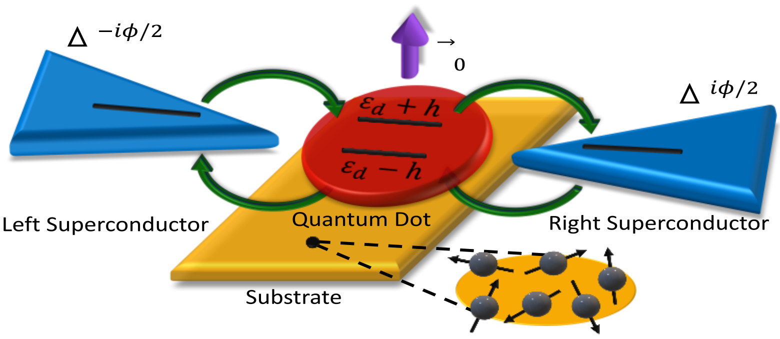

Fig.1: Scheme of the magnetic Quantum Dot Josephson junction under investigation. The s-wave superconducting leads have equal chemical potential μ and order parameter Δ, ε_d is the dot energy controllable via an external gate, h is the Zeeman splitting induced on the dot due to the presence of the external field $\vec{B}_0$, t is the hopping amplitude between the leads and the dot.

References

[1] R. Capecelatro, V. Brosco, G. Campagnano, P. Lucignano, *Phys. Rev. B* **108** (2023) 104508.

Magnetron Sputtered Superconducting $W_{75}Re_{25}$ Thin Films: Influence of N_2 Gas in the Deposition Process

(Poster)
Monday 16 September
18:00 – 19:30

F. Colangelo[1], F. Avitabile[2], Z. Mahdoumi Kakhaki[1], A. Di Bernardo[1], C. Cirillo[2], and C. Attanasio[1]

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Abstract

Tungsten Rhenium ($W_{75}Re_{25}$), particularly in its bulk form, has been identified as a promising superconductor, capable of manifesting multiple crystalline phases, each with distinct superconducting properties [1, 2]. Notably, $W_{75}Re_{25}$ beta phase (A15) can reach a superconducting critical temperature, T_c, up to 11 K, which is significantly higher than that of its alpha phase (BCC). Despite its potential, thin film studies of $W_{75}Re_{25}$ are absent in existing literature. This research focuses on the superconducting properties of $W_{75}Re_{25}$ thin films, examining both their fundamental physics and applicative perspectives. Our experiments involve sputtered films ranging from 3 to 100 nm in thickness and analyze how T_c and resistivity, ρ, vary with film thickness. X-Ray Diffraction (XRD) studies confirm the presence of both alpha and beta phases in the films. Furthermore, we investigate the impact of N_2 incorporation during deposition—a technique previously applied to pure W films [3, 4]—on the crystalline phases. XRD results indicate a shift in phase composition, notably featuring the beta phase and an amorphous phase. Both T_c and ρ increase, underscoring $W_{75}Re_{25}$'s potential for developing superconducting applications, including gated-controlled three-terminal devices, such as nano-cryotron (nTrons), and superconducting nanowire single photon detectors (SNSPDs).

References

[1] J. I. Federer, R. M. Steele, Nature, 205 (1965) 587-588.
[2] D. S. Easton, C. C. Koch, D. M. Kroeger, J. W. Cable, Philos Mag, 30:5 (1974) 1117-1134.
[3] J. A. Hofer, N. Haberkorn, Thin Solid Films, 685 (2019),117-122.
[4] V. C. Bagwe, R. Duhan, B. Chalke, J. Parmar, S. Basistha, P. Raychaudhuri, Phys Rev B, 109:10 (2024),104519.

Temperature-dependent photoconductivity in two-dimensional MoS_2 transistors

(Poster)
Monday 16 September
18:00 – 19:30

Sebastiano De Stefano[1], Nadia Martucciello[2], Arun Kumar[1], Ofelia Durante[1], Andrea Sessa[1], Adolfo Mazzotti[1], Enver Faella[3], Loredana Viscardi[1], Kimberly Intonti[1], Filippo Giubileo[2], Aniello Pelella[5], Paola Romano[4], Stephan Sleziona[6], Marika Schleberger[6], and Antonio Di Bartolomeo[1]

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The photoconductivity in monolayer MoS_2 back-gate transistors is studied as a function of temperature and pressure. The photocurrent increases linearly with the light intensity up to a maximum responsivity of ~30 A W^{-1} in air. Time-resolved photocurrent measurements confirm that the photoresponse is dominated by the photogating effect. The device shows slow photoresponse with two time constants that are attributed to the photobolometric effect and the desorption of adsorbates, respectively. An enhancement of the photocurrent is observed above room temperature and below the atmospheric pressure, that is when the photoinduced desorption of adsorbates such as O_2 and H_2O molecules is facilitated. Indeed, the light-induced removal of adsorbates from the surface of MoS_2 enhances the n-doping level and the current of the channel. Moreover, at lower pressures, the reverse mechanism of re-adsorption in dark conditions is suppressed and results in a persistent photocurrent. The study clarifies the photocurrent relaxation dynamics and unveils the key role of surface adsorbates in the optoelectronic properties of monolayer MoS_2 and other similar 2D materials.

References

[1] Di Bartolomeo, A., Kumar, A., Durante, O., Sessa, A., Faella, E., Viscardi, L., ... & Schleberger, M. (2023). *Materials Today Nano*, *24*, 100382.
[2] Kumar, A., Faella, E., Durante, O., Giubileo, F., Pelella, A., Viscardi, L., ... & Di Bartolomeo, A. (2023). *Journal of Physics and Chemistry of Solids*, *179*, 111406.
[3] Sleziona, S., Pelella, A., Faella, E., Kharsah, O., Skopinski, L., Maas, A., ... & Schleberger, M. (2023). *Nanoscale Advances, 5(24), 6958-6966.*
[4] Pelella, A., Grillo, A., Urban, F., Giubileo, F., Passacantando, M., Pollmann, E., ... & Di Bartolomeo, A. (2021). *Advanced Electronic Materials*, *7*(2), 2000838.
[5] Pelella, A., Kharsah, O., Grillo, A., Urban, F., Passacantando, M., Giubileo, F., ... & Di Bartolomeo, A. (2020). *ACS Applied Materials & Interfaces*, *12*(36), 40532-40540.

A Josephson phase battery

(Poster)
Monday 16 September
18:00 – 19:30

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A conventional battery converts chemical energy into a persistent voltage capable of powering electronic circuits. Similarly, a phase battery is a quantum device that provides a constant phase bias to the wave function within a quantum circuit, serving as a crucial component for quantum technologies that rely on phase coherence. In this study, we present the fabrication of a phase battery in a hybrid superconducting circuit. The device includes an InAs nanowire doped with unpaired spin surface states, proximized by superconducting aluminium leads. Our results reveal that the ferromagnetic polarization of the unpaired spin states effectively transforms into a persistent phase polarization φ_0 along the nanowire, resulting in an anomalous Josephson effect. By applying an external in-plane magnetic field, we can continuously adjust φ_0, thus allowing the quantum phase battery to charge and discharge. The observed symmetries of the anomalous Josephson effect under a vector magnetic field are in line with our theoretical model. These results demonstrate how the combined effects of spin-orbit coupling and exchange interaction create a strong coupling between charge, spin and superconducting phase, which can disrupt the phase rigidity of the system [1,2].

References

[1] Strambini, E., *et al.*. *Nature Nanotechnology* ***15*(8)** (2020) 656-660.
[2] Guarcello, C., *et al.*. *Physical Review Research* ***2*(2)** (2020) 023165.

Van der Waals BP/MoS_2 Heterostructures: Electrical and Optoelectronic Characterization

(Poster)
Monday 16 September
18:00 – 19:30

O. Durante[1,2], L. Viscardi[1], S. De Stefano[1], K. Intonti[1], A. Kumar[1], A. Pelella[3], F. Giubileo[2], O. Kharsah[4], L. Daniel[4], S. Sleziona[4], M. Schleberger[4], and A. Di Bartolomeo[1]

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In recent years, heterojunctions formed by stacking two-dimensional (2D) materials have attracted considerable interest because of their outstanding electronic and optoelectronic characteristics. These have paved the way for new device structures and uses. The combination of black phosphorus (BP) and molybdenum disulfide (MoS_2) is particularly noteworthy for its potential in creating state-of-the-art optoelectronic devices. This research explores the dynamics between BP, MoS_2, and chromium (Cr) contacts, shedding light on the electrical characteristics of a BP/MoS_2 heterojunction that exhibits rectifying behavior, mainly n-type conduction, and a significant ON/OFF current ratio of about 10^4 at ± 20 V. The higher unexpected current observed in the presence of a negative bias applied to both the MoS_2 and BP sides is clarified through an energy band model that includes a type II heterojunction at the BP/MoS_2 interface. In this case, Cr makes a Schottky contact with MoS_2 and an ohmic contact with BP. The BP/MoS_2 heterojunction also shows a remarkable photoresponse, which increases linearly with the incident light power, reaching a responsivity of 100 µA/W to white light with an incident power of 50 µW. Time-resolved photocurrent experiments show a fast response, with rise times of less than 200 milliseconds. This investigation confirms the peculiar electrical and photoresponse properties of van der Waals BP/MoS_2 heterojunctions, highlighting their promise for future optoelectronic technologies [1].

References

[1] Viscardi, L., *et al.*, *Surfaces and Interfaces* **49** (2024) 104445.

Crystal growth, superconductivity and Hall effect of Bi-Pd alloys

(Poster)
Monday 16 September
18:00 – 19:30

R. Fittipaldi[1], A. Guarino[1], D. Mayoh[2], M. Lettieri[1], G. Avallone[3], A. Romano[3], G. Balakrishnan[2] and Antonio Vecchione[1]

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In recent years, significant efforts have been devoted to exploring novel quantum materials with spin-triplet pairs to develop Majorana states [1,2]. Bi-based superconductors are considered promising candidates for realizing spin-triplet pairing due to their large spin-orbit coupling. In this study, we present an optimized method for synthesizing high-quality single crystals of α-BiPd and β-Bi_2Pd using the optical floating zone technique [1]. The composition and crystallinity of the synthesized crystals were analyzed using a scanning electron microscope with energy dispersive spectroscopy and electron backscattered diffraction. Additionally, the superconducting properties and Hall effect of both α-BiPd and β-Bi_2Pd single crystals were investigated through resistivity measurements.

References

[1] B.Q. Lv, T. Qian, H. Ding, Rev. Mod. Phys. **93** (2021) 025002.
[2] T. Shang, S.K. Ghosh, M. Smidman, D.J. Gawryluk, C.h. Baines, W. An Wang,Y. Xie, M.O. Chen, M. Ajeesh, E. Nicklas, M. Pomjakushina, M. Medarde, J.F. Shi, H. Annett, J.Q. Yuan, T. Shiroka, Npj Quantum Mater. 7 (2022) 35.
[3] R. Arumugam, R. Fittipaldi, A. Guarino, Daniel Mayoh, A. Ubaldini, M. Lettieri, G. Avallone, A. Romano, G. Balakrishnan, A.Vecchione, Journal of Crystal Growth **630** (2024) 127592.

Toward the optimization of SiO_2 and TiO_2-based metamaterials: Morphological, Structural, and Optical characterization

(Poster)
Monday 16 September
18:00 – 19:30

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In recent years, metamaterials have emerged as a crucial technology for designing sub-wavelength thick optical components capable of performing various optical functions. Among the others, these nanostructures could be employed to tune the refractive index, making them useful in various fields (from optoelectronic applications to gravitational wave detectors). In this work, nanostratified structures composed of alternating layers of silica (SiO_2) and titania (TiO_2) were proposed and fabricated using plasma-assisted electron beam deposition.

The composite consists of 38 TiO_2 layers, each with a nominal thickness of 2.0 nm, and 38 SiO_2 layers, each with a nominal thickness of 1.3 nm, for a total of 76 nanolayers and a total thickness of 125.4 nm. Structural, morphological, and optical properties of the as-deposited and annealed 76-nanolayer sample were explored by using Atomic Force Microscopy, X-Ray Reflectivity, Raman Spectroscopy and Spectroscopic Ellipsometry. In addition, a section analysis of the sample was performed by means of Scanning Transmission Electron Microscopy. By performing morphological analysis, a high uniformity of coverage and remarkable surface flatness was demonstrated. It was remarkable demonstrated that the amorphous phase is preserved upon annealing. Loss angle measurements are in progress at room temperature and the first results are very interesting.

Observation of microsecond-lived quantum states in a carbon-based circuit

(Poster)
Monday 16 September
18:00 – 19:30

B. Neukelmance[1,2,*], B. Hue[1,2,*], Q. Schaeverbeke[2], L. Jarjat[1], A. Théry[1], J. Craquelin[1], W. Legrand[1], T. Cubaynes[1], G. Abulizi[2], J. Becdelievre[2], M. El Abbassi[2], J.A. Suplizio[2], D. Stefani[2], A. Cottet[1,3], M.M. Desjardins[2], T. Kontos[1,3], M.R. Delbecq[1,3]

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Semiconductor quantum dots are an attractive platform for the realisation of quantum processors. To achieve coherent long-range coupling in this architecture, quantum dots have been integrated into microwave cavities [1, 2]. However, it has been shown that the coherence of these systems is then reduced compared to their cavity-free implementations. Here, we manipulate the quantum state of a suspended carbon nanotube double quantum dot with ferromagnetic contacts embedded in a microwave cavity. By performing quantum manipulations via the cavity photons, we demonstrate coherence times of the order of 1 μs, two orders of magnitude larger than those measured so far in any carbon quantum circuit and one order of magnitude larger than silicon-based quantum dots in comparable environment. This holds promise for carbon as a host material for spin qubits in circuit quantum electrodynamics.

References

[1] J. J. Viennot, M. C. Dartiailh, A. Cottet, T. Kontos, Coherent coupling of a single spin to microwave cavity photons. Science 349, 408–411 (2015).
[2] N. Samkharadze et al. , Strong spin-photon coupling in silicon. Science 359,1123-1127(2018).

Quantum resource variational principle

(Poster)
Monday 16 September
18:00 – 19:30

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Geometric methods in theoretical physics offer a powerful conceptual framework to set up theories and considerable heuristic power in the understanding of what a theory is trying to tell us. This is of fundamental importance in the field of quantum information, where most of the effort is indeed devoted to the understanding of the consequences of quantum theory. In this work [1], we set up an action principle [2] for quantum resources [3] and study the associated geodesics. In particular, we focus on the quantum resources of entanglement, coherence, and anti-flatness, that is, the non-triviality of the probability distribution after a measurement. Specifically, we explore how this principle can be harnessed to ascertain the accumulation of quantum resources along a path in the parameter manifold of the theory, optimising the given action. The geodesics described by this action are an extension of the potential-free case, i.e. the Fubini-Study metric, elucidated by previous authors in the context of the geometric approach to quantum circuits [4-6]. This framework serves as a stepping stone towards discussing a geometric theory of quantum resources. We offer a concrete 2-qubit example of using this approach and show some feasible new directions for this whole work.

References

[1] Iannotti, D. and Hamma, A. “Geometric methods in quantum information and entanglement variational principle.” International Journal of Geometric Methods in Modern Physics, Vol. 21, No. 10, 2440010 (2024)
[2] Carlini, Alberto, et al. "Time-optimal quantum evolution." Physical review letters **96.6** (2006): 060503.
[3] Chitambar, Eric, and Gilad Gour. "Quantum resource theories." Reviews of modern physics 91.2 (2019): 025001.
[4] Nielsen, Michael A., et al. "Quantum computation as geometry." Science **311.5764** (2006): 1133-1135.
[5] Nielsen, Michael A. "A geometric approach to quantum circuit lower bounds." arXiv preprint quant-ph/0502070 (2005).
[6] Nielsen, Michael A., et al. "Optimal control, geometry, and quantum computing." Physical Review A—Atomic, Molecular, and Optical Physics **73.6** (2006): 062323.

Chaos, Entanglement and Stabilizer Entropy in SYK model

(Poster)
Monday 16 September
18:00 – 19:30

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The Sachdev-Ye-Kitaev (SYK) model stands out as a key example of a strongly interacting quantum many-body system that lends itself to analytical approaches. It describes N interacting Majorana fermions in zero dimensions and has become a pivotal tool in condensed matter physics, where it is believed to model quantum critical non-Fermi liquids, characterized by the absence of quasi-particle excitations. In high-energy physics, the SYK model is equally significant due to its connection to holography and duality with two-dimensional gravity. In this work, we study the generalized SYK model, known as the SYK-q model, which incorporates all-to-all interactions involving q fermions. We calculate key quantum properties, including entanglement, non-stabilizerness, anti-flatness, and the Loschmidt echo, in the ground state of each Hamiltonian. Additionally, we investigate the perturbed SYK model under a quantum quench, where we evolve the ground state temporarily and compute the aforementioned quantities in the evolved state.

References

[1] A. Kitaev, Entanglement in strongly-correlated quantum matter p. 38 (2015).
[2] S. Sachdev and J. Ye, Physical review letters 70, 3339 (1993).
[3] S. Bravyi and A. Kitaev, Physical Review AˆaAtomic, Molecular, and Optical Physics 71, 022316 (2005).
[4] L. Leone, S. F. Oliviero, and A. Hamma, Physical Review Letters 128, 050402 (2022).
[5] E. Tirrito, P. S. Tarabunga, G. Lami, T. Chanda, L. Leone, S. F. Oliviero, M. Dalmonte, M. Collura, and A. Hamma, Physical Review A 109, L040401 (2024).

Local dynamics and detection of topology in spin-1 chains

(Poster)
Monday 16 September
18:00 – 19:30

Maiellaro Alfonso[1], Heré Aubin[2], Andrej Mesaros[3] and Pascal Simon[3]

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Antiferromagnetic spin-1 chains host the celebrated symmetry protected topological Haldane phase, whose spin-1/2 edge states were evidenced in bulk by, e.g., Electron Spin Resonance (ESR). Recent success in assembling effective spin-1 antiferromagnetic chains from nanographene and porphyrin molecules opens the possibility of local, site-by-site, characterization. The nascent technique of combined ESR-STM is able to measure the spin dynamics with atomic real-space resolution, and could fully reveal and manipulate the spin-1/2 degree of freedom. In this work, we combine exact diagonalization and DMRG to investigate the local dynamic spin structure factor of the different phases of the bilinear-biquadratic Hamiltonian with single-ion anisotropy in presence of an external magnetic field. We find that the signature of the Haldane phase is a low-energy peak created by singlet-triplet transitions in the edge-state manifold. We predict that the signature peak is experimentally observable, although for chains of length above N = 30 its energy should be first tuned by application of external magnetic field. We fully characterize the peak in real-space and energy, and further show its robustness to weak anisotropy and a relevant range of temperatures.

Predictive power of the Berezinskii-Kosterlitz-Thouless theory based on Renormalization Group for the BCS-BEC crossover in 2D superconductors

(Poster)
Monday 16 September
18:00 – 19:30

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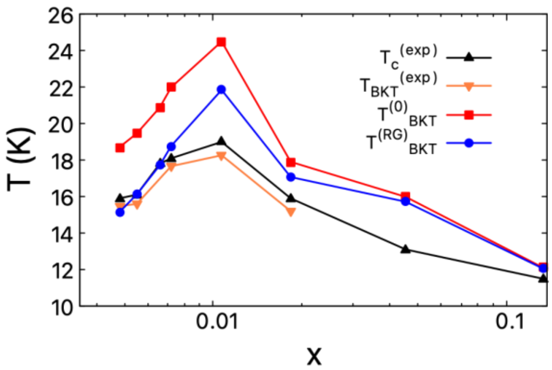
Recent experiments on 2D superconductors allow the characterization of the critical temperature and of the phase diagram across the BCS-BEC crossover as a function of density. We obtain from these experiments the microscopic parameters of the superconducting state at low temperatures by the BCS mean-field approach. For Li_xZrNCl, the extracted parameters are used to evaluate the superconducting phase stiffness and the Berezinskii-Kosterlitz-Thouless (BKT) critical temperature throughout the BCS-BEC crossover, by implementing the corresponding Renormalization Group (RG) approach. In this way, we make a quantitative test of the predictive power of the BKT theory for evaluating the critical temperature. The RG flow equations turn out to give a sizable renormalization of the phase stiffness and of the critical temperature, which is crucial to obtain a satisfactory agreement between the BKT theory and the experiments, in particular in the BCS-BEC crossover regime. We predict the temperature range where phase stiffness renormalization can be measured in Li_xZrNCl across the BCS-BEC crossover. Contrary to other microscopic theories of superconductivity, we find that the BKT theory can be exploited to evaluate quantitatively the critical temperature of 2D superconductors in different pairing regimes.

Figure. Comparison between experimental data (black and orange lines) and BKT theory for the critical temperature of Li 〖_x〗 ZrNCl as function of x. The red line is the BKT result without RG, while the blue line is the result including RG



References
[1] Nakagawa Y, Kasahara Y, Nomoto T et al 2021 *Science* **370**, 190

Topological Phase Diagram of an Interacting Kitaev Chain: Mean Field versus DMRG Study

(Poster)
Monday 16 September
18:00 – 19:30

Giovanni Nunziante[1,2], Alfonso Maiellaro[1,3], Claudio Guarcello[1,3], Roberta Citro[1,3]

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We present a theoretical analysis of the topological phase transitions in a Kitaev chain with nearest-neighbor Coulomb interactions. We employ a mean-field self-consistent approach and Density Matrix Renormalization Group simulations to investigate the stability of topological phases across different interaction regimes. Our findings reveal that the self-consistent mean-field model accurately captures the phase transitions between trivial and topological superconductivity. Furthermore, we identify conditions under which the topological phase is resilient against temperature variations. This work highlights the potential of using self-consistent mean-field methods to study topological properties in one-dimensional quantum systems.

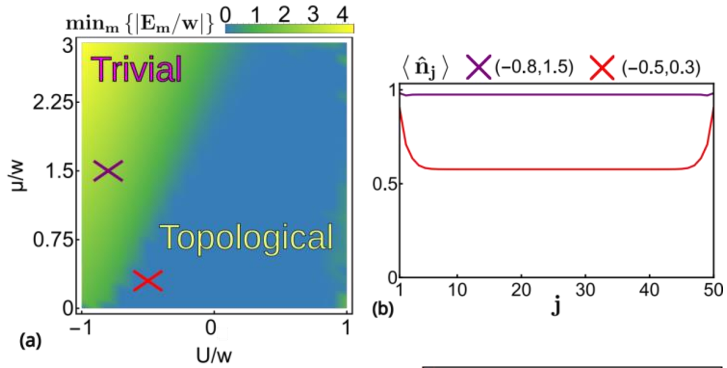

Figure 1: Results obtained from the self-consistent method at zero temperature: (a) Phase diagram in the $(U/w, \mu/w)$ parameter space. (b) Mean value of the local number operator on chain in both trivial and topological phases, indicated by the red and purple crosses in the phase diagram in panel (a).

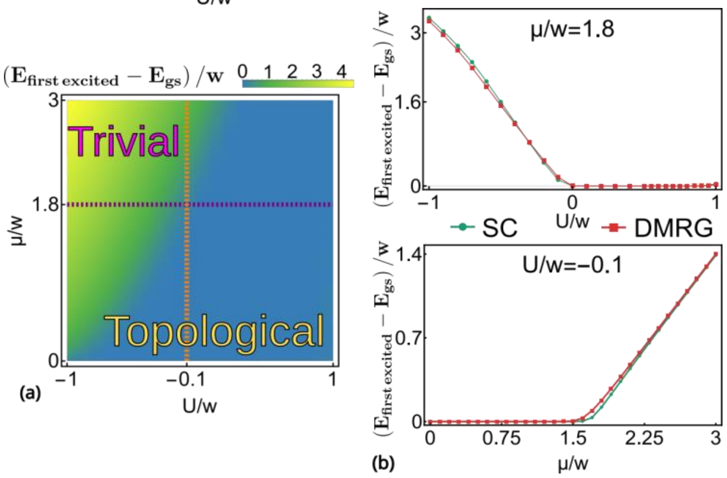

Figure 2: Comparison between the self-consistent zero-temperature method and DMRG: (a) Phase diagram in the $(U/w, \mu/w)$ parameter space obtained . (b) Lowest particle-like energy excitation in the self-consistent method in green and energy difference between the first excited state and ground state calculated by DMRG in red.

References
[1] G. Nunziante, A. Maiellaro, C. Guarcello, R. Citro, *Condens. Matter* **9** (2024) 20.

Electrical transport studies of van der Waals cuprate superconductors

(Poster)
Monday 16 September
18:00 – 19:30

Sanaz Shokri,[1,2] Christian N. Saggau,[1, 3, 4] Tommaso Confalone,[1, 2] Yejin Lee,[5, 1] Mickey Martini,[6, 1] Genda Gu,[7] Valerii M. Vinokur,[8] Kornelius Nielsch,[1, 2, 9] and Nicola Poccia[1, 10]

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Here we show electrical transport studies of van der Waals cuprate superconductors.

QUEnch mechanisms Study In supercONductors for Safe energy and energy Saving: the QUESTIONs project

(Poster)
Monday 16 September
18:00 – 19:30

A. Leo[1], M. R. Khan[1], N. Martucciello[1], A. Galluzzi[2], M. Polichetti[2,1], A. Troisi[3], G. Filatrella[3], C. Guarcello[2], R. Citro[2,1], M. Scuderi[4], A. Nigro[2,1], G. Grimaldi[1]

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QUESTIONs project aims to investigate pinning mechanisms preventing vortex motion and the features of this motion through the analysis of the critical parameters as a function of temperature, magnetic field, and field orientation. In fact, the vortex motion cannot be easily visualized, and it is therefore necessary to deduce its features through indirect measurements. By the same token, careful modelling is essential to interpret the experiments. In QUESTIONs key measurements in different extreme conditions of the critical voltage at which vortex motion becomes unstable and leads to a process known as *quench*, in the jargon of superconducting applications, are the project core.
Quench measurements will allow to estimate microscopic parameters as the quasiparticle energy relaxation time, and to grasp the microscopic scattering mechanisms of quasiparticles inside and outside the moving vortex core to discriminate between electronic non-equilibrium effects and pure thermal overheating origin of dissipation. Materials choice is a central issue also for superconducting power applications. The project will therefore check several materials, either belonging to the class of High-Tc Superconductors, or to the intermediate material, MgB_2, highly promising for applications.
Here, we present an overall picture of manipulating geometry and pinning to control vortex motion velocity in thin films of different materials, including Low-Tc Superconductors, ReBCO and Fe(Se,Te). The aim is dual: attaining higher vortex velocities pushing towards the operating limits in any superconducting device and gaining a deeper understanding of vortex and quasi-particle dynamics in extreme out-of-equilibrium conditions. We also show that a deep knowledge of the material anisotropy can boost high-speed limits of vortex dynamics, thus resulting in robust quenching currents against external fields.

Acknowledgments
Work partially supported by MUR-PRIN project "QUESTIONs" - grant no. P2022KWFBH and PON Research and Competitiveness 2007-2013 under grant agreement PON NAFASSY, PONa3_00007. Further, support by the European Cooperation in Science and Technology via COST Action CA19108 (HiSCALE) is acknowledged.

References
[1] G. Grimaldi, M. R. Khan, A. Leo, M. Scuderi, F. Rizzo, A. Augieri, G. Celentano, A. Galluzzi, M. Iebole, M. Polichetti, A. Nigro, V. Braccini, *iScience* 27 (2024) 109422.
[2] M. R. Khan, A. Leo, A. Nigro, A. Galluzzi, M. Polichetti, V. Braccini, M. Cialone, M. Scuderi, G. Grimaldi, *Materials* **14** (2021) 5289.
[3] A. Leo, A. Nigro, and G. Grimaldi, *Low Temp. Phys.* **46** (2020) 375.
[4] G. Grimaldi, A. Leo, F. Avitabile, N. Martucciello, A. Galluzzi, M. Polichetti, S. Pace, A. Nigro, *Nanotechnology* **30** (2019) 424001.

Pairing amplification induced by nonadiabatic effects on the electron-phonon interaction throughout the BCS-BEC crossover

(Poster)
Monday 16 September
18:00 – 19:30

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Nonadiabatic effects in the electron-phonon coupling are important whenever the ratio between the phononic and the electronic energy scales, the adiabatic ratio, is non negligible. For superconducting systems, this gives rise to additional diagrams in the superconducting self-energy, the vertex and cross corrections. In this work we explore these corrections in a two-dimensional single-band system through the crossover between the weak-coupling BCS and strong-coupling Bose-Einstein regimes. By focusing on the pseudogap phase, we identify the parameter range in which the pairing amplitude is amplified by nonadiabatic effects and map them throughout the BCS-BEC crossover. These effects become stronger as the system is driven deeply in the crossover regime, for phonon frequencies of the order of the hopping energy and for large enough electron-phonon coupling. Finally, we provide the phase space regions in which the effects of nonadiabaticity are more relevant for unconventional superconductors [1].

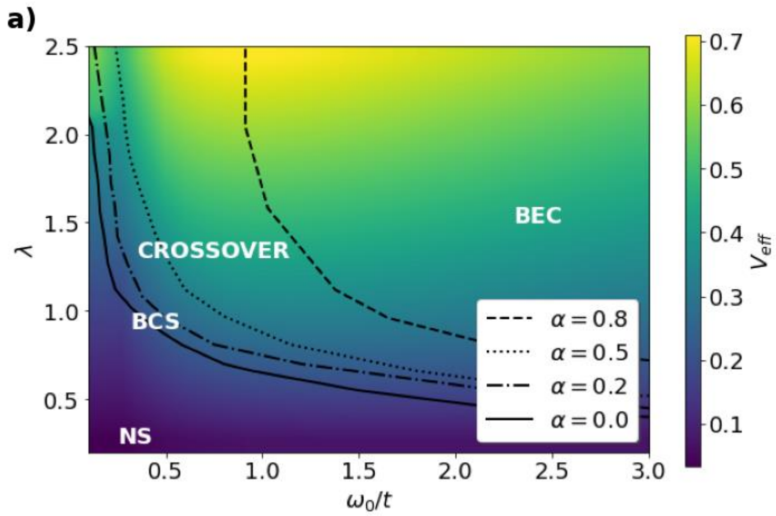

Fig: Phase diagram of the effective interaction amplification induced by nonadiabatic effects across the BCS-BEC crossover

References
[1] V. Velasco, G. Midei, M. Capone, and A. Perali, arXiv: 2406.13541 (2024), under consideration on Physical Review B.