Seminar of the Department of Low-Temperature Physics

NFPL098, summer term 2025

The seminar is held on **Monday at 2 p.m.** in the seminar room KFNT, **C 126** located in the building C (Kryopavilon) UK MFF, V Holešovičkách 2, Praha 8.

17. 2.

24. 2. **MakotoTsubota**, Osaka Metropolitan University, Japan, Direct observations of helical Kelvin waves; coupled turbulence in thermal counterflow

3. 3. **Tomáš Novotný,** KFKL, Theoretical approaches to correlated quantum dots coupled to superconducting leads

10. 3. **Jan Kuriplach,** KFNT, GENSIB project

17. 3. **Vendula Benešová,** KFNT, Hadron production in deeply inelastic scattering: COMPASS experiment
Tomáš Klásek, KFNT, Measurement of antiproton production: AMBER experiment

24. 3.

31. 3.

7. 4. **Filip Kadlec**, FZU, tba

14. 4. **Zdeněk Buk**, Fakulta informačních technologií ČVUT, The Road to AI: From Simple Neurons to Advanced Neural Network Applications

28. 4. **Ondřej Kaman**, FZU, Complex nanoparticles with magnetic cores and gold shells
5. 5. **Oleg Petrov**, MFF UK, Characterization of Zeolites with Solid-State NMR

12. 5. (*pravděpodobně) seminář v Peci*

19. 5. Marek Talíř tba _?

prof. Mgr. Jakub Čížek, Ph.D

doc. RNDr. Vojtěch Chlan, Ph.D.

prof. RNDr. Ladislav Skrbek, DrSc.

Abstracts:

Direct observations of helical Kelvin waves; coupled turbulence in thermal counterflow

MakotoTsubota, Osaka Metropolitan University, Japan

This seminar will explore the dynamics of Kelvin waves and the coupled turbulence in quantum fluids, providing new perspectives on quantum hydrodynamics.

1. **Direct Excitation of Kelvin Waves on Quantized Vortices [1]** We introduce controlled method for exciting Kelvin waves on a quantized vortex in superfluid 4He. By using a charged nanoparticle oscillating in response to a time-varying electric field, we successfully stimulated Kelvin waves on the vortex. The helical nature of these waves was confirmed through three-dimensional image reconstruction, providing visual evidence of their complex dynamics. Additionally, we determined the dispersion relation, phase velocity, and vorticity direction of the Kelvin waves, enhancing our understanding of quantum fluid behavior. This study sheds light on the dynamics of Kelvin waves and proposes a new approach to manipulating and observing quantized vortices in three dimensions, opening new avenues for exploring quantum fluid systems.
2. **Quantum Turbulence Coupled with Externally Driven Normal-Fluid Turbulence in Superfluid 4He Counterflow** The coupled dynamics of quantum turbulence (QT) and normal-fluid turbulence (NFT) in superfluid ^{4}He have been a central challenge in quantum hydrodynamics, particularly regarding the unresolved T2 state of QT. We numerically studied the interaction between QT and externally driven NFT in thermal counterflow. By using external forces to control the intensity of NFT and employing the fast multipole method to accelerate QT calculations, we showed that NFT enhances QT through mutual friction. The vortex line density follows the statistical law $L^{1/2}=\gamma V_{ns}$.. The obtained γis consistent with experimental values of the T2 state, supporting the hypothesis that the T2 state arises from NFT. We offer theoretical insights into the relationship between QT and NFT, contributing to a deeper understanding of quantum fluid turbulence.

[1] Y. Minowa, Y. Yasui, T. Nakagawa, S. Inui, M. Tsubota, M. Ashida, Nat. Phys. 1-6(2025).

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Theoretical approaches to correlated quantum dots coupled to superconducting leads

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I will present a brief overview of relatively simple theoretical approaches developed in our Prague group in past several years and applied to the problem of description of correlated quantum dots attached to the BCS superconducting leads. As a thorough Quantum Monte Carlo analysis [1] of the experimental data [2] showed realistic experimental setups can be even quantitatively captured by the Single Impurity Anderson Model (SIAM) with superconducting leads. Pioneering semi-analytical approaches have not matched the so far employed heavy numerical tools such as Numerical Renormalization Group (NRG) and/or Quantum Monte Carlo (QMC) in the ability of quantitatively predicting the properties of this model. However, we have shown recently that self-consistent perturbation expansion up to the second order in the interaction strength [3,4] yields at zero temperature and for a wide range of other parameters excellent results for the position of the $0-\pi$ impurity quantum phase transition boundary and the Josephson current as well as the energy of Andreev bound states in the 0-phase. This method can be also extended to the three-terminal situation with an extra normal lead corresponding to the experimentally interesting STM setup [5], where it allows to study phase-dependent Kondo physics. Furthermore, we have discovered exact identities connecting symmetric and asymmetric coupling situations which significantly reduce computational requirements in experimentally generic asymmetric setups [6] and provided simple approximate analytical formulas for the fitting of the phase boundaries from finite-temperature experimental data [7]. I will also briefly mention an exact mapping of a half-filled superconducting SIAM onto a normal SIAM with a structured semiconducting lead which simplifies some technical aspects of its NRG solution significantly [8,9] and a simple way of determination of the quantum critical point from finite-temperature QMC statistics [10]. Finally, the most recent extensions of those methods to more quantum dots [11] or superconducting leads [12] will be mentioned.

[1] David J. Luitz, Fakher F. Assaad, Tomáš Novotný, Christoph Karrasch, and Volker Meden, *Understanding the Josephson current through a Kondo-correlated quantum dot*, Phys. Rev. Lett. **108**, 227001 (2012).

[2] H. Ingerslev Jørgensen, T. Novotný, K. Grove-Rasmussen, K. Flensberg, and P. E. Lindelof, *Critical Current 0-π Transition in Designed Josephson Quantum Dot Junctions*, Nano Lett. **7** (8), 2441 (2007).

[3] M. Žonda, V. Pokorný, V. Janiš, and T. Novotný, *Perturbation theory of a superconducting 0-π impurity quantum phase transition*, Scientific Reports **5**, 8821(2015).

[4] M. Žonda, V. Pokorný, V. Janiš, and T. Novotný, *Perturbation theory for an Anderson quantum dot asymmetrically attached to two superconducting leads*, Phys. Rev. B **93**, 024523 (2016).

[5] T. Domański, M. Žonda, V. Pokorný, G. Górski, V. Janiš, and T. Novotný, *Josephson-phase-controlled interplay between correlation effects and electron pairing in a three-terminal nanostructure*, Phys. Rev. B **95**, 045104 (2017).

[6] Alžběta Kadlecová, Martin Žonda, and Tomáš Novotný, *Quantum dot attached to superconducting leads: Relation between symmetric and asymmetric coupling*, Phys. Rev. B **95**, 195114 (2017).

[7] Alžběta Kadlecová, Martin Žonda, Vladislav Pokorný, and Tomáš Novotný, *Practical Guide to Quantum Phase Transitions in Quantum-Dot-Based Tunable Josephson Junctions*, Phys. Rev. Applied **11**, 044094 (2019).

[8] Peter Zalom, Vladislav Pokorný, and Tomáš Novotný, *Spectral and transport properties of a half-filled Anderson impurity coupled to phase-biased superconducting and metallic leads*, Phys. Rev. B **103**, 035419 (2021).

[9] Peter Zalom and Tomáš Novotný, *Tunable reentrant Kondo effect in quantum dots coupled to metal-superconducting hybrid reservoirs*, Phys. Rev. B **104**, 035437 (2021).

[10] V. Pokorný and T. Novotný, *Footprints of impurity quantum phase transitions in quantum Monte Carlo statistics*, Phys. Rev. Research **3**, 023013 (2021).

[11] M. Žonda, P. Zalom, T. Novotný, G. Loukeris, J. Bätge, and V. Pokorný, *Generalized atomic limit of a double quantum dot coupled to superconducting leads*, Phys. Rev. B **107**, 115407 (2023).

[12] Peter Zalom, Martin Žonda, and Tomáš Novotný, *Hidden Symmetry in Interacting-Quantum-Dot-Based Multiterminal Josephson junctions*, Phys. Rev. Lett. **132**, 126505 (2024).

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