

The Schmid Transition in RSJJ: BKT Universality and transport properties

F. G. Capone¹, A. de Candia¹, V. Cataudella¹, R. Fazio^{1,2}, N. Nagaosa^{3,4}, C. A. Perroni¹, G. De Filippis¹

1. University of Napoli "Federico II", Department of Physics, Via Cinthia, 21, 80126, Napoli, Italy

2. The Abdus Salam International Center for Theoretical Physics (ICTP), Strada Costiera 11, 34151, Trieste, Italy

3. RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan

4. Fundamental Quantum Science Program (FQSP), TRIP Headquarters, RIKEN, Wako 351-0198, Japan

Abstract: This contribution introduces a novel binary order parameter, proving the Schmid transition belongs to the BKT universality class, and demonstrates a surprising absence of dissipation through out-of-equilibrium analysis.

The Schmid transition is a fundamental phase transition for the description of the resistively shunted Josephson junction (RSJJ), modeled as the parallel of a non-linear inductor (with Josephson energy E_J), a capacitance C (with typical energy $E_C = 4e^2/2C$), and a shunt resistance R_S . Schmid and Bulgadaev predicted an insulator-to-superconductor phase transition at $\alpha = R_q/R_S = 1$ [1,2], where $R_q = h/4e^2$ is the resistance quantum. However, the existence of this transition has recently been questioned both theoretically [3,4], and experimentally [5], sparking renewed interest in the transition itself and its consequences on the transport properties of the RSJJ. In this contribution, we demonstrate the nature of the transition by introducing a new binary order parameter S . Our results reveal that the transition belongs to the Berezinskii-Kosterlitz-Thouless (BKT) universality class [6,7], as evidenced in Fig. 1 by the logarithmic decay of the correlation functions around the critical point.

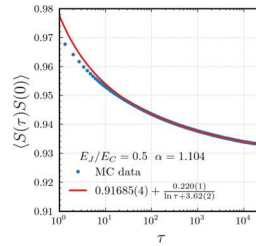


Fig. 1 Logarithmic decay of the correlations $\langle S(\tau)S(0) \rangle$ at the estimated critical point as an evidence of BKT criticality.

Furthermore, within the framework of linear response theory for resistivity, we show that the signature of the transition lies in the weight of the delta function D_Q at $\omega = 0$ (see inset Fig. 2 (a)) [7]. Strikingly, the absence of a low-frequency Drude peak in the response function $\Psi_{\text{reg},Q}(\omega)$ (see Fig. 2), leads us to conclude that the physics of the system does not involve dissipation. This behavior is further confirmed by a detailed analysis of the out-of-equilibrium system when a small current is injected.

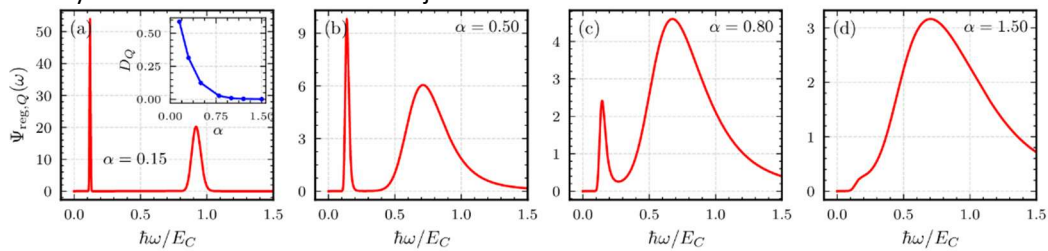


Fig. 2 Analytic continuation of the resistivity response function $\Psi_{\text{reg},Q}(\omega)$ on real frequencies via MaxEnt for (a) $\alpha = 0.15$, (b) $\alpha = 0.5$, (c) $\alpha = 0.8$, (d) $\alpha = 1.5$ at $E_J/E_C = 0.5$ and $\beta E_C = 100$. Inset (a): delta weight contribution D_Q as a function of α .

References

- [1] A. Schmid, "Diffusion and Localization in a Dissipative Quantum System", Phys. Rev. Lett. **51**, 1506 (1983).
- [2] S. Bulgadaev, "Phase diagram of a dissipative quantum system", ZhETF Pisma Redaktsiiu **39**, 315 (1984).
- [3] K. Masuki, H. Sudo, M. Oshikawa, and Y. Ashida, "Absence versus Presence of Dissipative Quantum Phase Transition in Josephson Junctions", Phys. Rev. Lett. **129**, 087001 (2022).
- [4] C. Altimiras, D. Esteve, C. Girit, H. Le Sueur, and P. Joyez, "Absence of a dissipative quantum phase transition in Josephson junctions: Theory" arXiv:2312.14754, (2023).
- [5] A. Murani, N. Bourlet, H. le Sueur, F. Portier, C. Altimiras, D. Esteve, H. Grabert, J. Stockburger, J. Ankerhold, and P. Joyez, "Absence of a dissipative quantum phase transition in Josephson junction", Phys. Rev. X **11**, 018002 (2021).
- [6] F. G. Capone, A. de Candia, V. Cataudella, N. Nagaosa, C. A. Perroni, and G. De Filippis, "A Clue on Small-Capacitance Josephson Junction: What to Expect from Cooper Pair Ideal Conductor and Ohmic Resistor in Parallel?", arXiv:2504.00258, (2025).
- [7] F. G. Capone, A. de Candia, V. Cataudella, R. Fazio, N. Nagaosa, C. A. Perroni, and G. De Filippis "Quantum Brownian Motion: proving that the Schmid transition belongs to the Berezinskii-Kosterlitz-Thouless universality class", arXiv:2603.16227, (2025).