Alexander Mirlin
Karlsruhe Institute of Technology

Non-equilibrium bosonization and singular Fredholm determinants.

We develop the bosonization technique for 1D many-body problems out of equilibrium [1] within the framework of the Keldysh action formalism. The method is employed to study an interacting quantum wire (Luttinger liquid) attached to two electrodes with arbitrary energy distributions. The non-equilibrium electron Green functions, which can be measured via tunneling spectroscopy technique and carry the information about energy distribution, zero-bias anomaly, and dephasing, are expressed in terms of Fredholm functional determinants of single-particle ``counting"operators. The corresponding time-dependent scattering phase is found to be intrinsically related to ``fractionalization" of electron hole excitations in the tunneling process and at boundaries with leads. We also use the developed formalism to calculate the full counting statistics of transmitted charge.

Particularly interesting is the case of distribution functions with multiple sharp edges (including the situation of population inversion). To analyze the results expressed as singular Toeplitz determinants, we develop an appropriate generalization of the Fisher-Hartwig conjecture. This yields the dephasing rates that are oscillatory functions of the interaction strength, as well as modified (non-equilibrium) exponents at each of the Fermi edges.

We further explore many-particle Green functions that, in particular, carry information about correlations in the fermionic distribution functions [2]. They are expressed in terms of a more general class of singular Fredholm determinants that arise from an interplay of multiple edges in time and energy spaces. We propose a general asymptotic formula for this class of determinants and provide analytical and numerical support to this conjecture. This allows us to establish non-equilibrium power-law singularities of many-particle correlation functions [3]. As an example, we calculate a two-particle distribution function characterizing correlations between left- and right-moving fermions that have left the interaction region.

Finally, we use a similar formalism to obtain an analytic result for the interference current (and, in particular, for the visibility of Aharonov-Bohm oscillations) in a model of the quantum Hall Mach-Zehnder interferometer [4]. Our results, which are in good agreement with experimental observations, show an intimate connection between the observed "lobe" structure in the visibility of Aharonov-Bohm oscillations and multiple branches in the asymptotics of singular integral determinants.

[1] D. B. Gutman, Y. Gefen, and A. D. Mirlin, Phys. Rev. Lett. 101, 126802 (2008); Phys. Rev. B 80, 045106 (2009); Europhys. Letters 90, 37003 (2010); Phys. Rev. B 81, 085436 (2010); Phys. Rev. Lett. 105, 256802 (2010); J. Phys. A: Math. Theor. 44, 165003 (2011); I.V. Protopopov, D.B. Gutman, and A.D. Mirlin, Lith. J. Phys. 52, 165 (2012).

[2] I.V. Protopopov, D.B. Gutman, and A.D. Mirlin, J. Stat. Mech. P11001 (2011).

[3] I.V. Protopopov, D.B. Gutman, and A.D. Mirlin, arXiv:1212.0708.

[4] S. Ngo Dinh, D.A. Bagrets, and A.D. Mirlin, arXiv:1302.2866.