Disordered thin-film superconductors: a machine learning enhanced mean-field study

We report results on our study of disordered thin-film superconductors. Such systems exhibit a rich variety of phenomena due to the interplay of Anderson localization and superconductivity. A hallmark effect is the enhancement of the critical temperature by disorder.
Studying these systems has proven quite challenging due to the difficulty of modeling interacting systems with broken translational invariance. We met this challenge in two ways:

1. We implemented a large-scale mean-field solver for disordered systems based on the Kernel Polynomial Method [1]. With this new solver, we were for the first time able to model systems of sufficient system size to answer critical open questions. In this presentation, we focus on the local density of states and local spectral gap fluctuations in disordered superconductors.
2. We apply novel machine learning methodology to study the phase diagram of disordered superconductor systems, for which standard methodology breaks down. Such a breakdown occurs, for instance, in systems with mean-field interactions or vacancies.

A few key results include: (i) the description of coherent picture of local density of states fluctuations formulated with both our analytical [2] and experimental [3] collaborators; (ii) the finding of a breakdown of the direct proportionality of superconducting order parameter and local spectral gap, as it is observed in translationally invariant BCS superconductors. Already for weak disorder, we find that only low correlations remain between order parameter and spectral gap; (iii) a demonstration that, in contrast to potential disorder, vacancies stabilize a topological superconducting phase and allow it to persist until very strong disorder.

[1] Matthias Stosiek, Bruno Lang, and Ferdinand Evers, PRB **101**, 144503 (2020)
[2] M. Stosiek, F. Evers, and I. S. Burmistrov PRR **3**, L042016 (2021)
[3] M. Lizée, M. Stosiek, I. Burmistrov, T. Cren, and C. Brun, PRB **107**, 174508 (2023)