Three way interplay of strong correlations, topology, and disorder in high temperature superconductors

Debmalya Chakraborty
Department of Physics and Astronomy, Uppsala University, Sweden

One of the major challenges in condensed matter physics is to understand how many interacting electrons form different phases of matter. One such exotic phase of matter formed solely due to the presence of interactions is superconductivity. Ever since their discovery, superconductors have found applications across diverse fields of science starting from medical science to high energy and astrophysics, apart from the long sought after applications, like lossless power transmission and magnetic levitation trains. The practical applicability of superconductors depends heavily on the temperature regimes where they exhibit superconductivity. It is largely believed that electron-electron interactions hold a key in achieving high superconducting transition temperatures. Recently, superconductors have been combined with topology to obtain topological superconductors with potential applications for topological quantum computation. Real-world materials bring in disorder as an additional important component. Taking an example of a high temperature superconductor, I will show how three way interplay of strong electronic correlations, topology, and disorder generates a new quantum phase of matter: a fully gapped "phase crystal" state that breaks both translational and time reversal invariance, characterized by a modulation of the d-wave superconducting phase co-existing with a modulating extended s-wave superconducting order. In contrast to conventional wisdom, this phase crystal state is remarkably robust to omnipresent disorder, but only in the presence of strong correlations, thus giving a clear route to its experimental realization [1]. I will further discuss how understanding the roles of interactions, topology, and disorder can not only answer various existing unsolved puzzles, but also provide pathways to discovering new materials with novel functionalities.

[1] D. Chakraborty et al., npj Quantum Materials 7, 44 (2022).