

Quantum criticality in the two-dimensional Hubbard model

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We study the normal-state, doping-driven phase diagram of the square-lattice Hubbard model using a four-patch dynamical cluster approximation combined with the numerical renormalization group as a cluster solver, which gives direct access to real-frequency dynamics at essentially zero temperature. In a parameter regime relevant for cuprates, $U = 7t$ and $t' = -0.3t$, we find a critical doping p^* that marks a continuous quantum phase transition between a pseudogap metal and a normal Fermi liquid. The transition is identified by a continuous collapse, from both sides, of the Fermi-liquid scale extracted from charge, spin, and d-wave pairing susceptibilities. This collapse produces a non-Fermi-liquid regime at intermediate energy scales, which appears to extend to arbitrarily low scales at p^* . As p^* is crossed from the normal Fermi liquid at $p > p^*$ into the pseudogap metal at $p < p^*$, the coherent low-energy spectral weight in the antinodal region is lost and replaced by a narrow, metallic pseudogap, while the nodal region evolves smoothly and remains comparatively coherent. This gives rise to Fermi arcs in the pseudogap metal at $p < p^*$, since the zero-frequency spectral weight remains large in the nodal region but is strongly suppressed in the antinodal region.

Furthermore, we study dynamical scaling in the quantum-critical fan of the pseudogap-metal to Fermi-liquid transition of the $t - t'$ Hubbard model, accessing real-frequency dynamics over several decades at arbitrary temperatures. Close to the critical doping, the local spin and cluster-current susceptibility spectra exhibit $x = \omega/T$ scaling of the form $\chi''(\omega, T) \sim \tanh(x/2)$, and the cluster contribution to the optical conductivity obeys $T\sigma'(\omega, T) \sim \tanh(x/2)/x$, implying a $1/T$ cluster dc-conductivity. In the scaling regime, the vertex contribution to the cluster optical response is much larger than the bubble contribution. We further find evidence for a marginal-Fermi-liquid nodal self-energy. This, together with the $1/T$ vertex contribution to the conductivity, implies strange-metal optical transport in the quantum critical region. Our results describe several qualitative aspects of several experimental observations.

[1] <https://arxiv.org/abs/2605.15059>.

[2] <https://arxiv.org/abs/2605.15060>.