Research Summary for “Mott Criticality as the Confinement Transition of a Pseudogap-Mott Metal”

In the peculiar world of quantum materials, electrons do not always behave as polite, independent particles. Sometimes, under the influence of strong repulsive interactions, they can freeze into an insulating state -- a phenomenon known as the Mott transition. Here, we describe a new theoretical framework that unites two mysterious aspects of such systems: the opening of a pseudogap, where some electronic states quietly disappear, and the collapse of the conventional theory that normally describes metals-what physicists call Fermi liquid behaviour.

Our story begins not with a solid block of material, but with a single electron thrust locally into an environment of mobile electrons. This is the famous quantum impurity problem, involving a strongly repulsive solitary actor embedded in a sea of other interacting electrons. Like a lonely diplomat in a foreign court, the impurity interacts with its surroundings, is very averse to sharing its duties, and its fate is deeply shaped by the medium in which it resides. We refine this model using the powerful machinery of the unitary renormalization group, a way of stripping away irrelevant details to expose the essential physics at low energies. The renormalization group approach transforms the complex physics of the system, tracking its evolution in a way reminiscent of the way in which water flows are tracked while cascading across a mountainous landscape: from mountain-top to valley-bottom.

From this microscopic vignette, we construct a grander picture. We stitch together the behaviour of many such impurities using a mathematical technique called tiling, akin to tiling a floor with intricate patterns derived from each local tile. In this way, we map the local dynamics at and near the impurity to the full momentum-space dynamics -- how electrons move in various directions -- of a full problem of interacting electrons on a two-dimensional lattice. What emerges from this intricate construction is a revelation: the ordinary metal does not fail all at once. Rather, it disintegrates in two acts, like a play with a tragic intermission. In the first act, we witness the rise of a shadowy character-the pseudogap. Here, some electrons continue to move freely, while others are trapped in ambiguous limbo. Locally, this arises from the Kondo effect, where local magnetic moments are partially neutralized by a sea of itinerant electrons -- but now the screening is selective, affecting only parts of the Fermi surface of the surrounding electronic environment. Curiously, the true low-energy excitations of this system are not the electrons we started with, as their lifetimes become vanishingly short. Instead, they are replaced with holes and doubly occupied sites that can disperse within the conduction bath. These excitations trace ghostly arcs instead of full circles in momentum space, a curious fingerprint observed in high-temperature superconductors.

Then comes the second act: a strongly interacting strange metal (which we call the *Mott metal*) remains, with excitations still able to move in narrow channels -- nodes, as physicists call them. The holes and doubles excitations span increasing lengthscales and entangled within the system, becoming truly long-ranged and devoid of any characteristic scales (of energy, length, momentum) precisely at the transition into the Mott insulator. The standard mathematical description of metals thus breaks down; the equations that once tamed electrons now yield infinities. This is the non-Fermi liquid state, a regime where no single-particle description survives, and the collective takes over completely. At the heart of this metamorphosis is the Luttinger surface, a kind of topographical map in energy-momentum space showing where electrons cease to exist as individual entities. This surface emerges selectively across momentum space, signifying not just a shift but a total rearrangement of how energy and presence--what physicists call spectral weight-are distributed in the system. It is not merely a phase transition, but a rewriting of the rules. Most profoundly, we find that the pseudogap is not a vague precursor or a thermal mirage: it is a bona fide quantum phase, governed by its own internal laws.

By following this route, we chart a new path to the heart of the Mott transition, one that goes beyond the confines of local quantum criticality (the currently dominant theory). In doing so, we uncover a richer landscape of electronic behaviour -- where strangeness is not a symptom, but a principle. A similar study of what happens upon doping the Mott insulator and strange metal with holes