Navigating Fermi Arcs

In solids, the Fermi surface is the boundary between occupied and unoccupied electron levels, just as the shoreline of the ocean is the boundary between water-filled and dry regions Earth. And, just like a shoreline surrounding a body of water, every Fermi surface should form a single unbroken loop. Consequently, the 1998 discovery of disconnected segments of the Fermi surface in cuprate superconductors – Fermi arcs – shocked and perplexed physicists, just as finding the edge of the world would shock a sailor today[1].

Recent attempts to resolve this conundrum focused on finding the "back side" of a Fermi arc, based on the belief that matrix elements, which govern the photo-emission process, hid it in a fog. Consequently, great excitement was generated when Meng, et al.[2] reported that they had found just the right conditions to pierce that fog and observe the back side. However, shortly afterwards, King, et al. [3] reported that the observation of Meng, et al. was a mirage; specifically, a reflection of the Fermi arc itself caused by the superstructure of the underlying lattice. In any event, all models predicting the formation of a small pocket to connect the ends of a Fermi arc have difficulty explaining the temperature dependence of the arc, which grows smoothly above T_c.[4]

In a study recently published in Nature Physics, researcher Ted Reber, along with co-workers in Prof. Dan Dessau’s group at the University of Colorado, performed angle-resolved photoemission spectroscopy (ARPES) at SSRL Beam Line 5-4 to determine the origin of Fermi arcs in the cuprates. The ability of ARPES to directly image the momentum states of electrons in a solid make it the ideal tool to study Fermi arcs, and the team’s work would not have been possible without the low-energy photons and excellent experimental resolution of Beam-line 5-4 at SSRL. The low photon energy enabled the team to isolate a single band from complicating features, such as the afore-mentioned superstructure, the incoherent background, the shadow bands, and so on. The beamline’s excellent energy resolution afforded the ability to resolve the superconducting gap, even very close to the node (<2°). To analyze the resulting spectrum, they used a new technique which called for the unorthodox step of integrating the ARPES spectrum along momentum to extract a spectral weight for the band. After normalizing to a reference Fermi edge they had a measure of the density of states for a single slice through the band structure. As tomography is the process of imaging a volume via individual slices, this technique determines what is called the tomographic density of states (TDoS). For quantitative analysis, the TDoS was fit to a conventional Dynes formula for the density of states for s-wave superconductors[5]. Even though the d-wave gap is momentum-dependent in the cuprates,
for each slice the gap is effectively single-valued, so Dynes’s original form holds. This fit returns two parameters: the superconducting gap magnitude, \( \Delta \), and the pair-breaking rate, \( \Gamma \).

With this analysis technique, they determined the following two facts. First, \( \Delta \) changes very little with temperature, even through \( T_C \), suggesting Cooper pairs continue to exist in the normal state. Second, \( \Gamma \) is unconventionally large and strongly temperature-dependent, shifting weight from the peaks into the gap and effectively filling it. The constancy of \( \Delta \) indicates that even in the normal state the band is still bent back and does not cross the Fermi energy. Instead it lurks just below the surface like a reef. Consequently, the Fermi arc is not a true Fermi surface and need not form a complete loop. The large and temperature-dependent \( \Gamma \) shifts real weight from the gap edge to the Fermi energy, forming the Fermi arc. Consequently, the arc is a byproduct of the intense competition between pair-forming and pair-breaking processes, just like a storm causes waves to crash on a reef, creating the froth and foam that gives the illusion of a coastline. Far from inconsequential, this foam of non-quasiparticle states is a fascinating candidate to explain the non-Fermi liquid physics that dominates the normal state of the cuprates.

**Primary Citation**

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**References**


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