Some Observations about Cuprate Superconductors

More than 40 years after the 1986 discovery of high-temperature superconductivity in the cuprates, the question of "what is the pairing mechanism?" in these materials is still hotly debated.

Why?

Here are some reasons:

The cuprates are "correlated electron materials," which means that simple single-particle concepts are often not helpful for understanding the microscopic physics of these materials.

There are many other correlated-electron phases that compete with superconductivity in the same doping, pressure, and temperature range. Some of these phases appear to have some of the features of superconductivity, but do not have all of the ingredients to make a *bona fide* superconductor. In particular, many correlated superconductors have ordered magnetic phases, typically anti-ferromagnetic, nearby in the doping/temperature/pressure phase diagram.

As a result the "normal state" of the cuprates is not well understood.

This is manifested by the question of "how does the superconducting state form out of phase X?" where "X" includes states such as the "pseudogap phase", "strange metal phase," "striped phase," "doped fluctuating antiferromagnetic insulator phase," etc.

From quantum matter to high-temperature superconductivity in copper oxides

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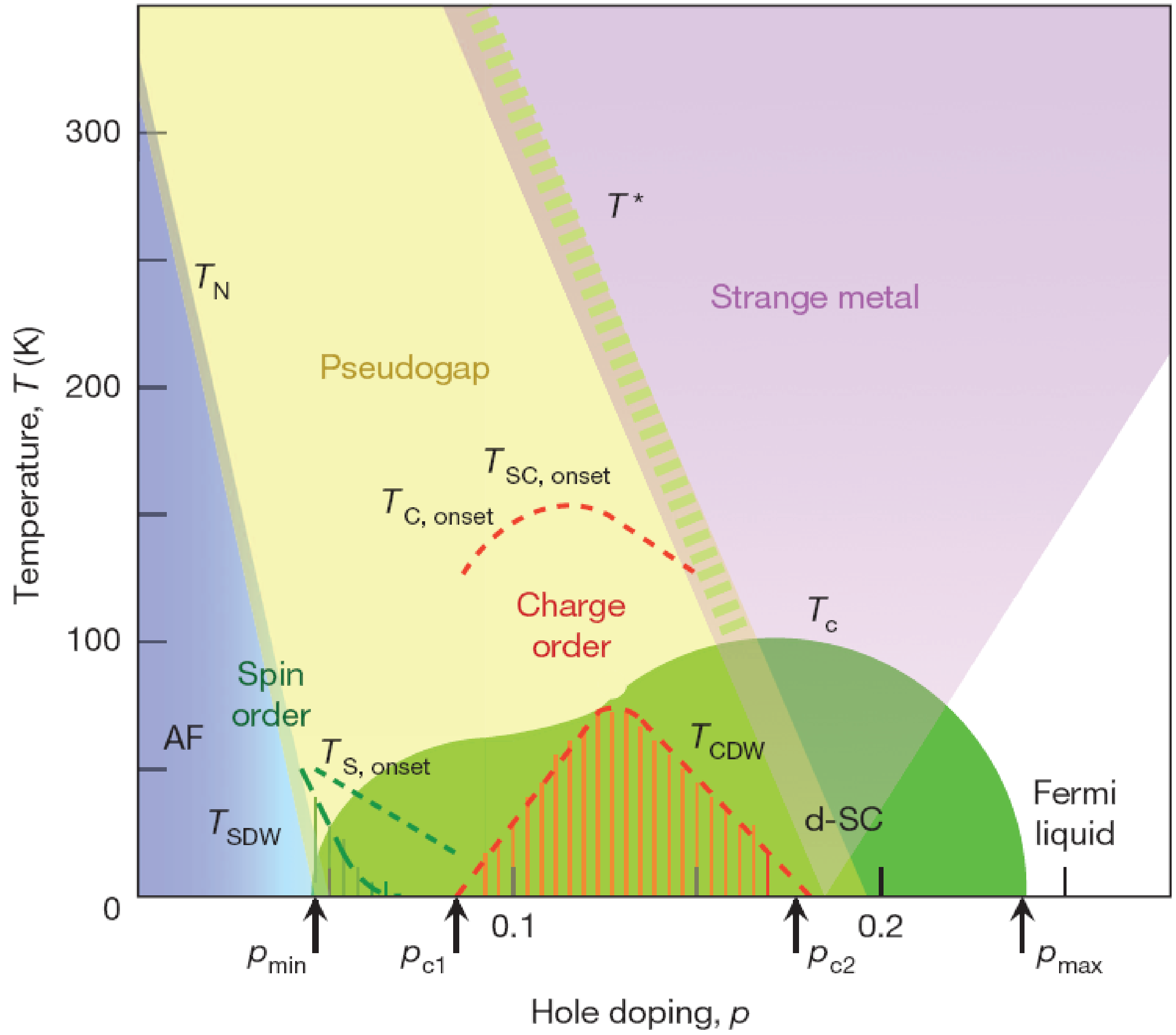

Figure 2 | Phase diagram. Temperature versus hole doping level for the copper oxides, indicating where various phases occur. The subscript 'onset' marks the temperature at which the precursor order or fluctuations become apparent. $T_{S,\,onset}$ (dotted green line), $T_{C,\,onset}$ and $T_{SC,\,onset}$ (dotted red line for both) refer to the onset temperatures of spin-, charge and superconducting fluctuations, while T^* indicates the temperature where the crossover to the pseudogap regime occurs. The blue and green regions indicate fully developed antiferromagnetic order (AF) and *d*-wave superconducting order (d-SC) setting in at the Néel and superconducting transition temperatures T_N and T_c, respectively. The red striped area indicates the presence of fully developed charge order setting in at T_{CDW}. T_{SDW} represents the same for incommensurate spin density wave order. Quantum critical points for superconductivity and charge order are indicated by the arrows.

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Some Approaches to Understanding Cuprate Superconductivity

Referring to the cuprate phase diagram on the previous slide…

Approaching from the "Fermi liquid" high-doping side, there has been some success in understanding cuprate superconductivity in terms of (repulsive) electron-electron interactions mediated by anti-ferromagnetic spin fluctuations. This is the 'conservative approach' that makes use of modifications to existing BCS theory and concepts. However, this approach is largely at a loss to explain any of the features on the left side of the phase diagram.

Approaching from the "AF" antiferromagnetic insulator side, there are more 'radical' approaches to understanding the onset of superconductivity from a doped Mott insulator. This includes quantum spin-liquid phases that naturally give rise to superconductivity (RVB), or fractionization of electrons/holes into spin and charge degrees of freedom, along with many other interesting ideas.

One of the main difficulties is that there are many nearly-degenerate and inter-twined correlated electron phases competing with superconductivity, as shown in the phase diagram.

These ideas were expressed by Patrick Lee (MIT) in a talk at the 2026 Materials and Mechanisms of Superconductivity Conference