Competing orders in the cuprate superconductors

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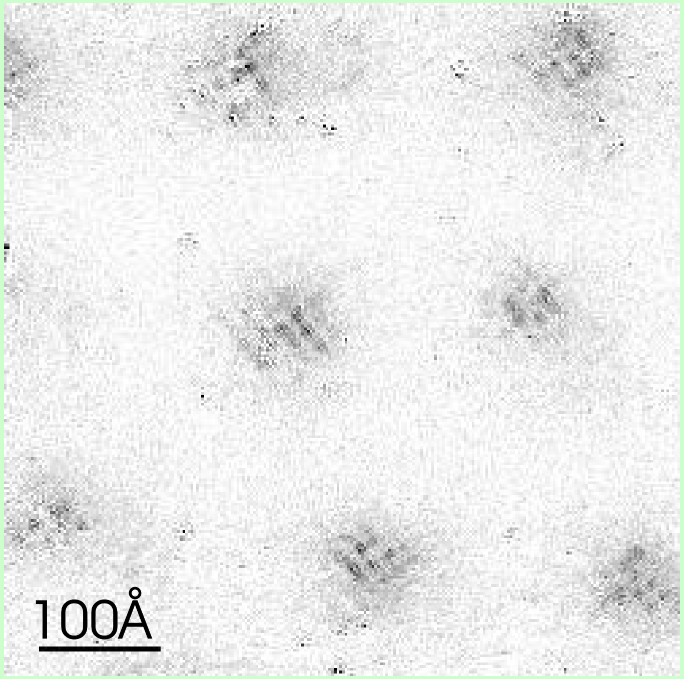
The cuprate superconductors conduct electricity without measurable resistance at high temperatures. This, and their other unusual physical properties, raise important questions on the fundamental quantum physics of interacting electrons. We have a proposed theory in which their properties may be understood by a "competition" between superconductivity and the order in other nearby phases that these materials can also form. **Vortices** of the superconductor play a central role in our theory: these are "whorls" of flowing electrons which carry an elementary quantum unit of circulation. We have shown that each vortex also carries a periodic modulation in the density of electrons, linked to the competing order.



A nanoscale image of vortices in a cuprate superconductor (J.E. Hoffman *et al.*, *Science* **295**, 466 (2002)). Pairs of electrons flow perpetually in circles around each dark spot. Notice the atomic scale "checkerboard" modulations within each spot. Similar structures were predicted by our theory, as a fundamental quantum property of a vortex.

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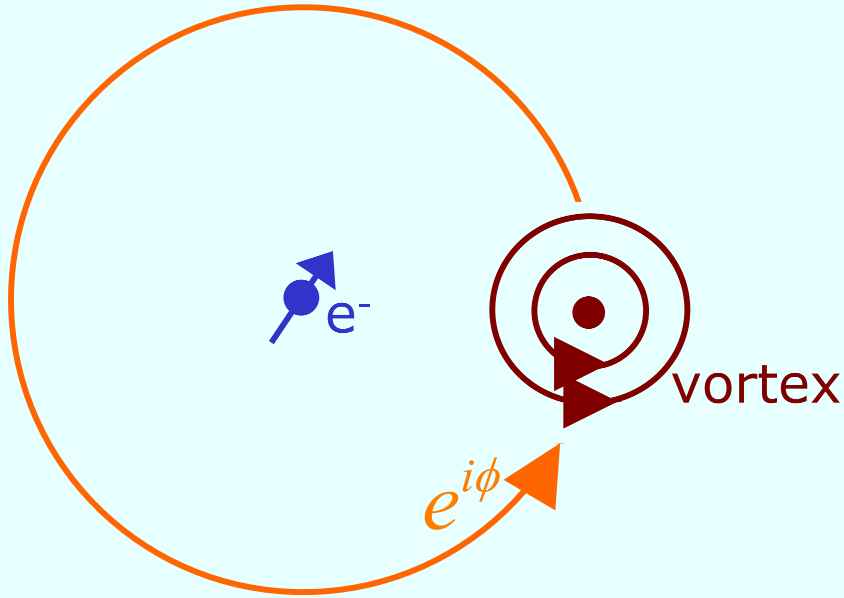
A key ingredient in our theory is the idea that each vortex is a quantum degree of freedom in its own right: it has its own wavefunction and exhibits quantum interference effects. Furthermore, the vortices come in multiple "flavors", with the number of flavors determined by the average density of electrons. The periodic density modulations at the core of each vortex are then an **interference pattern** between the different flavors of vortices, as they undergo quantum "zero-point" motion.



The wavefunction of a vortex acquires a phase factor each time the vortex encirles an electron—this phase is responsible for the quantum interference effects.

Young scientists trained: Lorenz Bartosch, Adrian Del Maestro, Adam Durst, Predrag Nikolic, Kwon Park, Anatoli Polkovnikov, Stephen Powell, Matthias Vojta, Ying Zhang. A text book on quantum phase transitions was written, and numerous public lectures were presented: detailed and accessible information on these is available on the web site http://pantheon.yale.edu/~subir