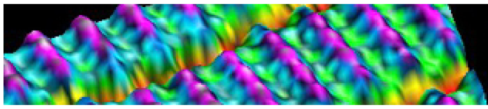

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A Class of Their Own

New Superconductors Defy Conventional Models

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New generations like to set themselves apart from their predecessors, and it appears superconducting materials are no exception.

Assistant Professor Norman Mannella and his colleagues have found that the latest arrivals in the superconducting family—compounds of iron and arsenic—have intriguing characteristics that differentiate them from both their BCS ancestors and the younger cuprate high-temperature superconductors (HTSCs).

Superconductivity dates to the 1950s when scientists discovered that phonons—vibrations in a crystal lattice— cause electrons to form pairs that can carry current with no resistance. The BCS Theory, named for John Bardeen, L.N. Cooper, and J.R. Schrieffer, was the standard in superconductivity studies for 30 or so years, until the cuprates came along. Comprising copper and oxygen, cuprates become superconductors at much higher temperatures than conventional materials, though still far below room temperature (~300° Kelvin). Yet how the electrons pair up in the HTSCs has still to be determined conclusively, thus defying our understanding of condensed matter physics.

In 2008 the playing field got even more interesting when Japanese scientists found that compounds made from iron and arsenic (Fe-As) become superconductors at increasingly higher temperatures, up to 55° Kelvin. Researchers are now studying how these materials compare with both traditional BCS superconductors and cuprates. The more that's known about what causes this phenomenon, the closer scientists come to a comprehensive theory.

Mannella and his colleagues performed experiments in the soft (low-energy) x-ray regime such as Angle Resolved Photoemission, (ARPES), x-ray absorption (XAS) and x-ray emission (XES) spectroscopy, typically carried out at several synchrotron radiation facilities including the Advanced Light Source in Berkeley, California; the Advanced Photon Source at Argonne, Illinois, and Elettra in Trieste, Italy. The combined use of these techniques constitutes a uniquely powerful approach for looking at the electronic structure of novel materials.

The team has performed experiments on different families of Fe-As materials such as $CeFeAsO_{0.8}9F_{0.11}$ and $Ba(Fe_{1-x}Co_x)_2As_2$, with the results showing a marked departure from earlier studies on copper-oxygen compounds. The data reveal that the electrons in this material are itinerant in nature; much more delocalized than in the cuprates, where the interactions are stronger. Here, as Mannella explained, "the electrons have room to move around," making them more akin to metals, while in cuprates "the narrower electron bands force the electrons to interact more strongly."

In "Evidence for strong itinerant spin fluctuations in the normal state of $CeFeAsO_{0.8}$ $9F_{0.11}$ iron-Oxypnictides," published in *Physical Review Letters* in December, the research team also reported evidence of itinerant spin fluctuations. This is a significant result, considering that electronic spin is responsible for a material's magnetism, and that the latter appears to be in competition with superconductivity, as displayed in the general phase diagram, a sort of map of a given material showing how its phases relate to temperature and composition. The detection of magnetic fluctuations by means of magnetic probes has so far remained elusive because of the extremely fast time scales involved. Mannella's experiment provides a strong and unique test case for the occurrence of itinerant magnetic fluctuations, whose detection was made possible by the rapid time scales in the photoemission process. By finding direct signatures of magnetic fluctuations in a prototypical oxypnictide material, the work clarifies some modalities of the interactions between magnetism and superconductivity.

Further peculiar characteristics of the Fe-As superconductors have been reported in the team's latest paper, "Evidence for three-dimensional Fermi-surface topology of the layered electron-doped iron superconductor $Ba(Fe_{1-x}Co_x)_2As_2$," published in the June issue of *Physical Review B* as an Editor's Suggestion and a Rapid Communications article. They investigated the electronic structure of iron-arsenic samples using ARPES, a technique that gives a more precise picture of a material's electronic structure. They found a distinctive signature for three-dimensionality in the Fermi-surface—the dividing line between occupied and unoccupied electronic states in a material. Mannella explained that these results are significant because they provide a unique example of a superconductor with a layered structure that is three-dimensional, rather than two-dimensional, in nature—markedly different from other layered superconducting materials, such as cuprates. This may indicate that reduced dimensions in materials may not be a prerequisite for superconductivity.

Taken together, these findings suggest that the underlying physics and the origin of superconductivity in these materials are likely to be quite different from those of the cuprate high-temperature superconductors, and also from those of MgB2 and BCS-like electron-phonon superconductors. These new superconductors can't easily be categorized with previously studied materials, and should be considered a class of their own.

Co-authors on the *Phys. Rev. Lett.* paper are: Federica Bondino, Elena Magnano, Marco Malvestuto, and Fulvio Parmigiani representing CNR-INFM Laboratorio Nazionale, Sincrotrone Trieste S.C.p.A., and the University of Trieste Department of Physics, all in Trieste, Italy; as well as Michael A. McGuire, A.S. Sefat, Brian C. Sales, Rongying Jin, and David Mandrus of the Oak Ridge National Laboratory Materials Science and Technology Division; and Ward Plummer of UT Physics and Louisiana State University.

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