which may be metabolically costly or evolutionarily complex. Even so, it is not clear how the signals in the 12 midband spectra receptors are read out by the brain. Natural spectra are not monochromatic and the animal would need to distinguish changes in brightness, perhaps caused by highlights and shadows, from colorful objects. The visual system would have to compare the signals in single midband receptors with those of others, as in normal color opponency. A simple way would be divide the response of each receptor type by an overall brightness signal derived by summing the outputs of all midband receptors. An alternative is to compare signals of the three receptor types in each midband row, in effect giving the animal four independent trichromatic systems.

The poor color discrimination found (*3*) is also a puzzle. It would be interesting to understand how stomatopods use color in their daily lives. For instance, in conflicts mantis shrimps seem to assess their opponent's color to decide whether to fight, allowing them to avoid dangerous opponents (*9*). If so, they are likely to need to discriminate smaller differences than those found when they are trained to associate color with food (*3*).

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10.1126/science.1249614

PHYSICS

Lifting the Fog of Complexity

Combining surface- and bulk-sensitive experimental probes may help to solve the complexity underlying high-temperature superconductivity.

Dirk K. Morr

Identifying the microscopic origin of materials' complex properties is one of the main intellectual challenges in condensed matter physics. The emergence of complexity is often tied to novel forms of collective behavior driven by strong interactions. Unconventional superconductors, such as the high-temperature (cuprate) or iron pnictide superconductors, and heavy fermion compounds are archetypical examples for materials in which the competition and entwining of collective forms of behavior give rise not only to a complex phase diagram but also to unexpected properties that have resisted all attempts of a theoretical explanation. In the phase diagram of the cuprate superconductors, these properties are associated with the pseudogap region, a region located in close proximity to magnetic, charge, and superconducting orders. Whether the competing nature of these various orders is the underlying cause for the pseudogap and its unconventional properties is one of the central questions in this field. On pages 390 and 393 in this issue, Comin *et al.* (*1*) and da Silva Neto *et al.* (*2*) answer a crucial part of this question by elucidating the relation among superconductivity, charge order, and the pseudogap region, as well as establishing the ubiquitous nature of charge order across different families of cuprate superconductors.

The cuprates can be tuned from insulating antiferromagnets to unconventional superconductors via doping (chemical substitution of elements), giving rise to a complex phase diagram (see the figure, panel A). Between the antiferromagnetic (AFM) and superconducting (SC) phases resides the pseudogap region, where many of the material's properties strongly deviate from those predicted by Landau-Fermi liquid theory, one of the cornerstones of condensed matter physics (*3*). The region's name arises from the (incomplete) transfer of the material's quantum states from low to high energies, which creates an energetic pseudogap. The proximity of the pseudogap region to antiferromagnetism and superconductivity, combined with the observation of static charge order (CO) in some cuprate families (*4*), has given rise to the suggestion that the pseudogap region represents an incipient charge (*5*), magnetic (*6*), or superconduct-

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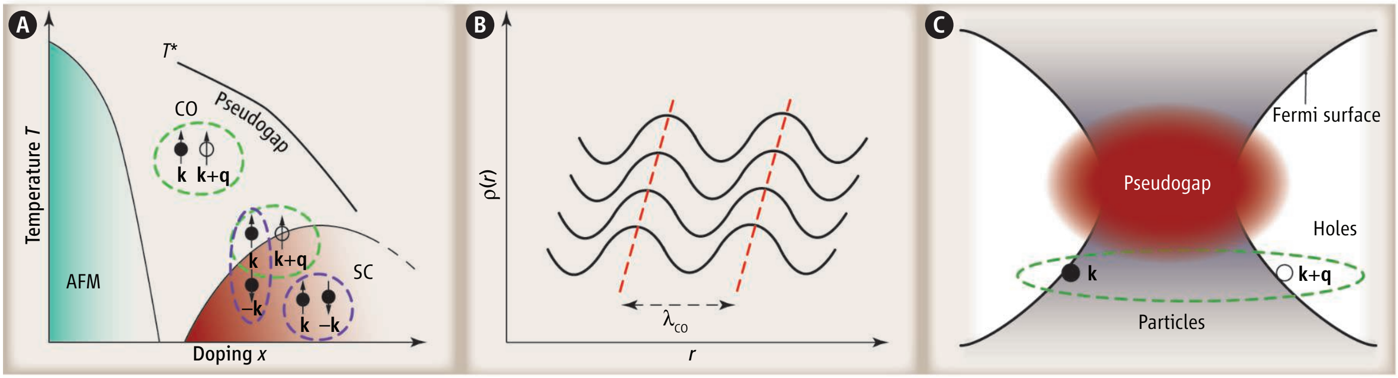

Unraveling complexity. (**A**) Schematic phase diagram of the cuprate superconductors. Charge order (CO) involves pairing of an electron (solid circle) and hole (empty circle) with the same spin ↑ and momenta **k** and **k** + **q** (green dashed ellipse), whereas superconductivity arises from pairing of two electrons with opposite spins, ↑ and ↓, and momenta **k** and –**k** (blue dashed ellipse). (**B**) Charge order implies spatial oscillations in the electron density, ρ(r). (**C**) Quantum states (in momentum space) involved in the formation of charge order (electron, solid black circle; hole, open black circle) and the quantum states affected by the pseudogap (red area).

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ing order (*7*), arises from competing orders (*8*), or is tied to an insulating Mott state (*9*).

Trying to identify the relation among charge order, magnetic order, superconducting order, and the pseudogap region presents a "chicken-or-egg" problem: Does the proximity to magnetic order induce superconductivity and the pseudogap, or does the pseudogap facilitate charge order, thereby suppressing both magnetism and superconductivity? Although these questions have been the topic of many debates, no consensus has been reached to date. Lifting this "fog of complexity" is important, as it is common to many strongly interacting systems in condensed matter physics, nuclear physics (*10*), and biology (*11*).

The experiments by Comin *et al*. and da Silva Neto *et al*. provide a powerful new approach to address this issue. Combining surface-sensitive scanning tunneling microscopy (STM) and angle-resolved photoemission spectroscopy (ARPES) experiments with bulk resonant elastic x-ray scattering (REXS) has enabled a comprehensive view of the relation among charge order, superconductivity, and the pseudogap in the bismuth-based family of high-temperature superconductors. With STM experiments probing the spatial structure of charge oscillations (see the figure, panel B) and REXS allowing the complementary detection of these oscillations in momentum space, the emergence of a dynamical charge order below a characteristic temperature T_{CO} is demonstrated. The spatial wavelength λ_{CO} of these charge oscillations is similar to that observed in La-based (*4*) and Y-based (*12*) cuprate superconductors; hence, this work establishes that dynamical charge order is a ubiquitous phenomenon in the high-temperature superconductors.

The observation by Comin *et al*. that T_{CO} approximately coincides with the onset temperature T^* of the pseudogap implies a close relationship between charge order and the pseudogap. However, which of them is the chicken and which is the egg? To answer this question, both groups investigated the quantum states taking part in the formation of these two phenomena. Charge order emerges from the pairing of an electron of momentum **k** with a hole (a missing electron) of momentum **k** + **q**, where $|\mathbf{q}| = 2\pi/\lambda_{CO}$ (see the figure, panel A). The electron and hole involved in the pairing process are located near the Fermi surface, an imaginary line in momentum space separating electrons and holes. By using the Fermi surface extracted from ARPES experiments, both groups identified the electron and hole quantum states participating in the formation of the dynamical charge order (see the figure, panel C). Are these quantum states the same as those being affected by the emergence of the pseudogap? Both groups provide a resounding no to this question: The quantum states involved in the formation of the charge order lie outside the region in momentum space that is involved in the formation of the pseudogap (see the figure, panel C). The conclusion is that it is the pseudogap that facilitates the formation of the charge order.

Another important part of the puzzle is revealed by da Silva Neto *et al*. through the observation that with the onset of superconductivity at T_c, the strength of the charge order weakens, ultimately vanishing at temperatures well below T_c; this demonstrates the competing nature of superconductivity and charge order (*12*). Because superconductivity requires the pairing of an electron with another electron of opposite spin and momentum, the results of da Silva Neto *et al*. imply that the pairing partner of an electron changes from being a hole at temperatures above T_c (giving rise to charge order) to being an electron below T_c (giving rise to superconductivity), with some superposition of these two types of pairing possible in the vicinity of T_c (see the figure, panel A). The competition between charge order and superconducting order therefore reflects the nature of two competing pairing tendencies that cannot be simultaneously satisfied.

The studies by Comin *et al*. and da Silva Neto *et al*. represent a major breakthrough in dissolving the fog of complexity surrounding the cuprate superconductors. Nonetheless, many questions still remain: What is the origin of the pseudogap? Is the competition between different types of order responsible for the cuprates' many unconventional properties? The comprehensive, multiprong approach adopted by Comin *et al*. and da Silva Neto *et al*. is a promising way forward in investigating these and many other open questions posed by complex systems.

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10.1126/science.1248868

IMMUNOLOGY

The Fiery Side of HIV–Induced T Cell Death

Gaurav D. Gaiha[1] and Abraham L. Brass[2]

A cytosolic protein that senses fragments of HIV-1 DNA triggers the death of uninfected CD4 T cells.

In untreated HIV-1 infection, the progressive destruction of CD4 T cells gives rise to a devastating number of opportunistic infections—the hallmark of AIDS. Yet, it remains unclear how HIV-1 inexorably depletes these essential immune cells. Most of the dying CD4 T cells are uninfected "bystanders" that self-destruct upon exposure to HIV-1 DNA products generated during aborted infection (*1*). Doitsh *et al*. (*2*) and a report by Monroe *et al*. on page 428 in this issue (*3*) show that these truncated fragments of HIV-1 DNA trigger CD4 T cell demise through an intense inflammatory cell death pathway—called pyroptosis—after their recognition by an intracellular DNA sensor (*4*, *5*).

Although HIV-1–induced CD4 T cell death had long been attributed to apoptosis (*6*, *7*), two host cell proteases, caspase-1 and caspase-3, are activated in bystander CD4 T cells by nascent HIV-1 genomic DNA (*1*). Whereas caspase-3 is associated with the classical pathway of apoptotic cell death, caspase-1 elicits "pyroptosis" (from the Greek for "fire fall-

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Lifting the Fog of Complexity
Dirk K. Morr (January 23, 2014)
Science **343** (6169), 382-383. [doi: 10.1126/science.1248868]

Editor's Summary