

camera, the collaboration hopes to refine its dark-matter mapping of the COSMOS field and extend it to higher redshifts. In addition to charting dark matter, the COSMOS collaboration examines, quite generally, how galaxies at high redshifts differ from galaxies in the present epoch.³ Scoville calls it paleocosmology. "COSMOS," he says, "is revealing, for the first time, the largest structures as they form in the early universe."

Looking beyond the *HST*, the collaboration hopes for a specialized orbiter that could produce deeper and more finely resolved dark-matter maps over regions of sky very much larger than the COSMOS field. To that end, COSMOS has joined the *SNAP* collaboration

led by Saul Perlmutter at LBNL. *SNAP* is one of several contending orbiter proposals to investigate dark energy by searching for high-redshift supernovae. But it is the only contender designed to map dark matter while it's patrolling for supernova explosions.

Bertram Schwarzschild

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Diffraction and modeling solve the structure of ytterbium-cadmium quasicrystals

This complex icosahedral quasicrystal forms from remarkably few types of geometrical clusters.

Where are the atoms? Per Bak posed this question about the positions of atoms in icosahedral quasicrystals¹ two years after their discovery in 1984. But despite thousands of papers published during the subsequent two decades, not one quasicrystal structure is known with the detail and accuracy that crystallographers can claim for normal crystals. The strange nature of quasicrystals accounts for the difficulty.² Judging by the sharp Bragg peaks in their diffraction patterns, quasicrystals can possess a long-range order comparable to the most perfectly crystalline material. But unlike normal crystals, quasicrystals also possess a rotational symmetry that forbids packing into a repeated array of unit cells. Consequently, they lack periodic translational order and a straightforward path from Bragg peaks to structure.

The sensitive interaction of x rays with atomic electrons makes x-ray diffraction foremost among the methods available to determine the arrangement of atoms in a crystal. X rays reflected from the lattice planes produce a set of Bragg peaks of various intensities, with each peak characterized by a vector that measures the momentum transfer. For normal crystals, it takes just three integers—Miller indices—to label the reflections, from which a map of the triply periodic electron density can be reconstructed, provided one can also infer the phases of the reflected waves.

The lack of periodic order in quasicrystals complicates the analysis of their diffraction data. Calculations are done in the framework of hyperspace crystallography, a mathematical approach that treats a quasicrystal as a three-dimensional slice through a structure that is periodic in a higher-dimensional space. In that framework, a quasicrystal structure is defined by arrangements of 3D hypersurfaces in 6D space—in contrast to a normal crystal, which is defined by arrangements of 0D points, the atoms, in 3D space.

To determine the physical structure, the crystallographer must go through the arduous process of determining the positions, sizes, and detailed shapes of those hypersurfaces, sometimes called occupation domains, through a complete 6D analysis of the diffraction spectrum. Strictly speaking, the occupation domains are regions where electron densities are concentrated in the 6D unit cell. To recover a 3D perspective, one then cuts a slice through that 6D cell.

Based on that kind of procedure, researchers led by Hiroyuki Takakura from Japan's Hokkaido University propose the most complete structural model to date for a type of icosahedral quasicrystal alloy made of ytterbium and cadmium.³ Takakura and company observed 5024 unique x-ray diffraction peaks, an order of magnitude larger set of reflections than typically used to analyze intermetallic alloys such as brass

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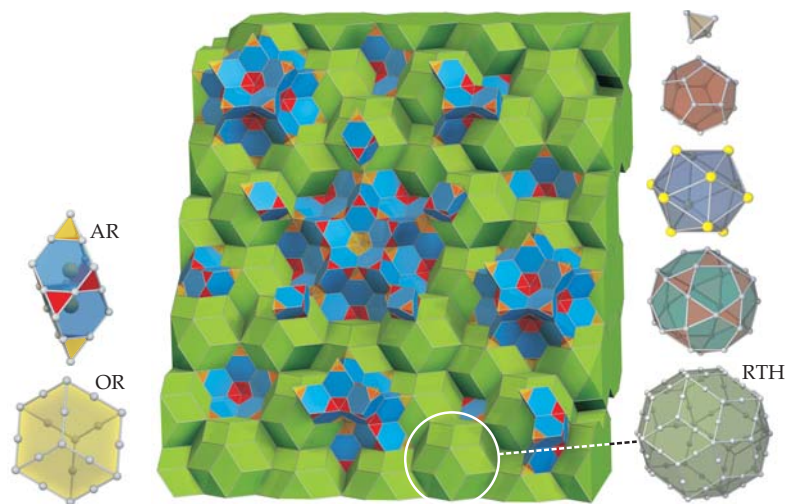
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Three-dimensional structure of an icosahedral ytterbium–cadmium alloy. All of the alloy's atoms (Yb in yellow, Cd in gray) form a quasiperiodic lattice composed of just three geometrical motifs: the rhombic triacontahedron with its successively smaller subshells that nest inside, the acute rhombohedron, and the obtuse rhombohedron. The RTH makes up the bulk of the quasicrystal. The AR and OR link the RTH clusters together and fill in the gaps to preserve the fivefold icosahedral symmetry; obtuse rhombohedra, hidden here, are embedded below the surface. The cog-wheel complex (center) and stellate polyhedra (top left and middle right) are recurring geometrical arrangements that self assemble. (Image adapted from ref. 3.)

or bronze. “Considering the quasicrystal’s high symmetry, that’s a quantity of data in reciprocal space matched only by the very largest biomolecules,” comments Cornell’s Veit Elser.

With just two elements, Yb–Cd offers the advantage of chemical simplicity. Until a few years ago, most researchers thought that only ternary

quasicrystals could be stably formed. In 2000 Takakura and coauthor An Pang Tsai, then at the National Research Institute for Metals in Tsukuba, Japan, identified $\text{YbCd}_{5.7}$ as quasicrystalline, and it remains one of only two known stable binary quasicrystals (see PHYSICS TODAY, February 2001, page 17). Moreover, the large difference in

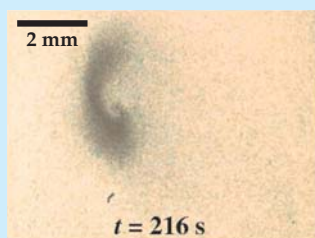
atomic number between the two elements ideally suits the system for x-ray diffraction.

X-ray diffraction, however, captures the spatially averaged structure. Some atomic sites appear to be only partially occupied—that is, a site might be occupied at some locations in the sample, while equivalent sites remain vacant

physics update

Supplementary material related to these items can be found at www.physicstoday.org.

New blood-separation technique inspired by Einstein’s tea leaves. Many medical diagnostic tests, including those for cholesterol levels, blood chemistry, and liver and thyroid function, are performed on blood plasma—the liquid part of the blood that’s left after all cells and cellular components are removed. Obtaining purified blood plasma usually requires a lab with a large centrifuge, but scientists at Australia’s Monash University have developed a new process based on the same principle that causes stirred tea leaves to accumulate at the bottom center of a teacup, a phenomenon first explained by Albert Einstein in the 1920s. A tiny amount of blood enters a microfluidic chamber, and a needle tip is



placed at an angle just above the surface of the blood. With a sufficient voltage applied to the needle, air near the tip is ionized and the resulting “ionic wind” sweeps across the surface of the blood, causing it to circulate. To satisfy the boundary conditions, a secondary bulk meridional flow arises that carries the microscopic particles—red blood cells in the Monash experiments—in a downward spiral along the chamber’s sides and radially inward at the bottom to a stagnation point at the center. The figure shows the separated cells collecting at the bottom after just a few minutes. The scientists say the technology could be incorporated into a low-cost, credit-card-sized device, but it may still be 5–10 years away from mass production. (D. R. Arifin, L. Y. Yeo, J. R. Friend, *Biomicrofluidics* **1**, 014103, 2007; <http://bmf.aip.org>.)

—TB

Sizing the synaptic cleft. Unlike the transistors in a computer chip, the neurons in our brains are not directly connected to each other. A roughly 20-nanometer gap, the synaptic cleft, separates a neuron’s output terminal from the input terminal of the next neuron in line. Signals cross the cleft as bursts of molecular ions called neurotransmitters. Once across, the neurotransmitters attach to receptors and trigger excitatory or inhibitory responses. Neurotransmitters come in several varieties, as do receptors, and the lateral area covered by a cleft varies several-fold from neuron to neuron. Yet the cleft height remains close to 20 nm. To find out why, Dmitri Rusakov of University College London and Leonid Savtchenko of Dnepropetrovsk National University in Ukraine developed a physical model. Narrowing the gap speeds transmission, as one would expect, but it also increases the electrical resistance of the intracleft medium. For a wide range of parameters, such as cleft area, diffusion coefficient, and number of receptors, the model yields an optimum cleft height of 15–20 nm, which matches the natural value. Evolution doesn’t always produce the best designs, but given the importance of transmitting information inside our brains, it’s not surprising that cleft height should be optimized. (L. P. Savtchenko, D. A. Rusakov, *Proc. Natl. Acad. Sci. USA* **104**, 1823, 2007.)

—CD

Chaos on a chip. Semiconductor lasers are normally sensitive to perturbations that can induce unstable or noisy behavior. As the lasers become integrated into tiny photonic circuits, such chaotic nonlinearities might become magnified and thwart any desired uses of the circuitry. Mirvais Yousefi and his colleagues at the Eindhoven University of Technology in the Netherlands have developed a method to investigate nonlinearities in coupled lasers and have found surprising regularities. The researchers use a pair of lasers so close to each other on a chip that each affects the operation of the other. By monitoring the system’s output dynamics as a function of the pump current, the researchers could directly visualize the period-doubling route

elsewhere. The effect is to blur the electron-density distribution in the 6D unit cell. The intrinsic disorder creates ambiguities that, despite the huge data set, prevent the unique assignment of every atom to its own specific site.

Takakura and company therefore had to interpret their recent diffraction data in concert with a model based on what are called approximants, crystalline phases whose compositions vary ever so slightly from the quasicrystal but whose structures are periodic and well known. Comparing the structures of the cubic approximants YbCd_6 and $\text{Yb}_{13}\text{Cd}_{26}$ with the reconstructed electron density of the quasicrystal, the team realized that the largest common building block for the approximants, a rhombic triacontahedron (RTH) decorated by 92 Cd atoms on its edges and vertices, also makes up the bulk of $\text{YbCd}_{5.7}$ (see the figure on page 24).

Like a nested set of Russian dolls, four subshells fit concentrically inside the RTH. The oddball among them is the four-sided tetrahedron, whose symmetry breaks the otherwise fivefold

icosahedral symmetry of the rest of the lattice. The tetrahedron's Cd atoms are likely to rotate among several symmetry-equivalent orientations, as they do in the YbCd_6 approximant when temperatures rise above 100 K.

Only two other geometrical motifs are required to reconstruct the quasicrystal lattice: acute and obtuse rhombohedra that link the RTH clusters together. One can liken the researchers' approach to assembling the pieces of a puzzle in which every atom is assigned a plausible position. The x-ray data confirm the model's prescription of where Yb and Cd reside within the various clusters and reveal the packing and distribution of those clusters in the lattice.

The 3D slab pictured here represents a finite part of their solution. The cogwheel complex, the stellate polyhedron, and their fragments illustrate the rich variety of shapes that can form locally from particular arrangements of acute and obtuse rhombohedra.

A strength of the model, according to Carnegie Mellon University's Michael Widom, lies in its flexibility:

Though deterministic, the model accounts for certain degrees of freedom in the arrangement of building blocks while the linkages between clusters are preserved. Clusters may dynamically and subtly flip from one configuration to another. It remains unclear to what extent quasicrystals are stabilized by adopting an ideal, deterministic arrangement of clusters that minimizes the system's energy or by adopting an ensemble of arrangements that maximizes its entropy. But one can now ask whether the new structural elements found in the quasiperiodic phase provide any energetic dividend. That would be a step toward answering an even more fundamental question than Bak's: Why should quasicrystals form at all?

Mark Wilson

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to chaos. They discovered that integrated optics show intrinsically nonlinear dynamics but that the nonlinear behavior is remarkably stable over the life of the chip and reproducible from one batch of chips to another. Thus, according to Yousefi, far from being a problem, the dynamics can be exploited to optimize the integrated photonic circuits. (M. Yousefi et al., *Phys. Rev. Lett.* **98**, 044101, 2007.) —PFS

Treating industrial wastewater with solar energy. In the so-called Fenton reaction, an iron cation, Fe(II) , gets oxidized to Fe(III) , while hydrogen peroxide (H_2O_2) gets reduced to OH^- and the hydroxyl radical $\text{HO}^\bullet$, which reacts with a great many organic substances. In water, the Fe(III) eventually converts back to Fe(II) , and the process can begin again. Although chemically very efficient at removing organic pollutants from water, the Fenton reaction requires UV or visible radiation (below 400 nm) to efficiently reconvert Fe(III) to Fe(II) in the last step. A team of researchers in Brazil, led by Claudio Nascimento of the University of São Paulo, has now explored the feasibility of using sunlight instead of expensive UV lamps to expedite that crucial step in the process. Using demonstration reactors, such as the parabolic-trough reactor shown here, the scientists ran a series of



experiments, typically for several hours in the afternoon under various sky conditions. They found that in the photo-Fenton process, sunlight worked effectively at degrading various pollutants, including silicone polymers from the textile industry, pesticides, phenols, and hydrocarbons. Overall, no new pollutants are created, residual Fe(III) can be precipitated as iron hydroxide, and residual H_2O_2 spontaneously decomposes into water and molecular oxygen. (C. A. O. Nascimento et al., *ASME J. Sol. Energy Eng.* **129**, 45, 2007.) —SGB

A step toward tomography of protons. In medical tomography, a planar slice of tissue is imaged and its three-dimensional structure is built up by stacking the planar views. By analogy, physicists at the Thomas Jefferson National Accelerator Facility in Virginia are attempting to image the quarks inside protons, one planar slice at a time, in momentum space. The probe is an intense beam of electrons and the target is liquid hydrogen. The physicists seek rare events called deeply virtual Compton scattering (DVCS) in which an incoming electron sends a virtual photon (a high-energy gamma ray) ahead of it. The virtual photon scatters from one of the elementary quarks in the proton and a real gamma ray re-emerges, leaving the target proton intact. Detection of the outgoing electron and photon provides information about the status of quarks inside the proton. For example, the probability of a quark's spatial position inside the proton, transverse to the direction of the virtual photon, can be related to the angle and energy of the outgoing gamma ray. In high-energy electron scattering, the square of the transferred four-momentum (Q^2) from electron to quark determines the spatial resolution. Beyond a certain point, however, a larger Q^2 does not provide greater resolving power because individual point-like quarks have no structure of their own. That the present experiment shows the scattering to be independent of Q^2 above about 2 GeV^2 is evidence that the technique is indeed imaging the distribution of the elementary quarks inside the proton. (C. Muñoz Camacho et al., *Phys. Rev. Lett.* **97**, 262002, 2006.) —PFS ■