Chandra's resolution is so good, says CfA's Tucker, "you'll see shock waves from galaxies falling into the cluster." Chandra will also observe active galaxies, whose brilliance at radio and other wavelengths is fueled by gas falling into a mammoth black hole; Meg Urry at STScI hopes to find out whether active galaxies can thrive in isolation or whether they have to live in clusters of other galaxies to keep the black hole well fed.

Garmire will use Chandra to reobserve a tiny patch of sky called the Deep Field, which Hubble observed in exquisite detail at optical wavelengths, seeing galaxies in the farthest reaches of the cosmos. "Lots of [optical Deep Field] objects are ho-hum things," Garmire says, but the same field in x-rays should show galaxies filled with hot young stars, helping astronomers understand the universe's history of star formation. Chandra may also pick out black holes at that great distance, allowing astronomers to test the possibility that black holes are born small and have grown larger over cosmic history. And like every new instrument, Chandra is certain to find something completely unexpected, says Harvey Tananbaum, director of the Chandra X-ray Observatory Center: "My favorite observation is going to be the one I couldn't have told you about today."

Such far-reaching, serendipitous, interdisciplinary astronomy was the reasoning behind NASA's Great Observatories program, in which Chandra is the third of four. (The Compton Gamma Ray Observatory and Hubble preceded it, and a planned infrared telescope called SIRTF will follow.) These ambitious missions suffer from lengthy time scales and high costs, but Schreier says nothing else offers as good a chance for fundamental discoveries. Agrees NASA's Alan Bunner: "You can do breakthrough science with small missions if you're clever and lucky, but usually it takes breakthrough observatories."

For now, says Murray, "seeing the light at the end of the tunnel and knowing it's not a train, I'm so excited you can't imagine."

–ANN FINKBEINER

Ann Finkbeiner is a writer in Baltimore.

EVOLUTIONARY BIOLOGY

Gaining New Insight Into the Molecular Basis of Evolution

By tying mutations in the sequences of visual proteins to altered function, researchers get a handle on how those changes may influence fitness

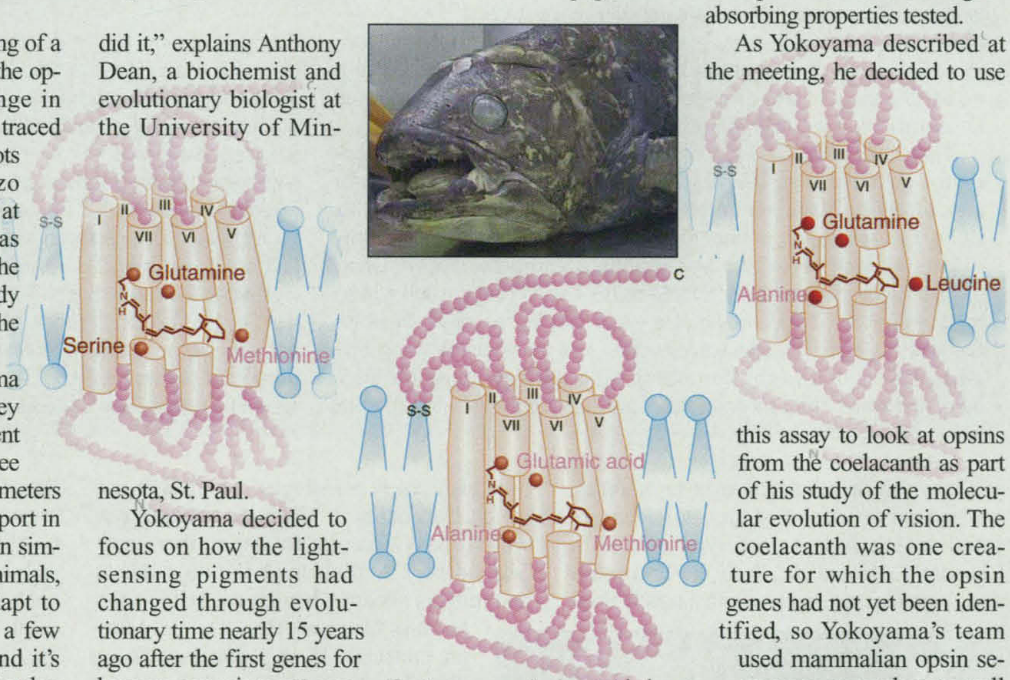
Every step in evolution, from a darkening of a moth's pigment to the development of the opposable thumb, is caused by a change in molecules. But biologists have rarely traced adaptive changes to their molecular roots in genes and proteins. Now Shozo Yokoyama, an evolutionary geneticist at Syracuse University in New York, has studied how natural selection works at the molecular level in a fish that is already celebrated in textbooks of evolution: the "living fossil" called the coelacanth.

At a meeting* last month, Yokoyama and his colleagues described how they pinpointed the changes in visual pigment genes that enabled the coelacanth to see in the dim light of the deep ocean, 200 meters below sea level. And in an upcoming report in *Genetics*, the group describes changes in similar genes from a wide range of other animals, which may have enabled them to adapt to their particular habitats. "There's just a few changes being driven by selection, and it's hard to ferret those out," says Charles Aquadro, an evolutionary geneticist at Cornell University in Ithaca, New York. "What Yokoyama has done is really clever."

The work may have applications beyond evolutionary biology, in the practical realm of biotechnology and protein engineering. "If you want to be able to engineer enzymes to carry out novel reactions, what better way [to design them] than by looking at how nature did it," explains Anthony Dean, a biochemist and evolutionary biologist at the University of Minnesota, St. Paul.

Yokoyama decided to focus on how the light-sensing pigments had changed through evolutionary time nearly 15 years ago after the first genes for human eye pigment proteins, which are called opsins, were cloned, an achievement that prompted the cloning of these genes from many more species. He wanted to see not just which changes took place during the evolution of a particular species but how each one affected the protein's function and the organism's ability to see. "It was very important to me to be able to manipulate these molecules," he recalls.

Other researchers had already devised one opsin assay. It involves putting an opsin gene, with or without specific mutations, into monkey kidney cells growing in laboratory dishes, giving the cells time to produce the opsin, and then adding the second component of the visual pigment, the light-absorbing chromophore, to the cells. Then the complete pigment can be purified and its light-absorbing properties tested.



Custom eyes. Amino acid changes yielded two pigments (circles) that are better adapted than the ancestral opsin *(center)* for deep-sea vision in the coelacanth *(top).*

As Yokoyama described at the meeting, he decided to use this assay to look at opsins from the coelacanth as part of his study of the molecular evolution of vision. The coelacanth was one creature for which the opsin genes had not yet been identified, so Yokoyama's team used mammalian opsin sequences as probes to pull out similar genes from the coelacanth genome. This search picked up two genes belonging to the rhodopsin family, plus a third gene that appeared to be incapable of producing a complete protein.

Rhodopsins are generally most sensitive to green light of 500 nanometers—a longer wavelength than that of the light penetrating down to where coelacanths live. To identify which amino acid changes in the coelacanth

CREDITS: (TOP) LAURENT POLYAUD; (BOTTOM THREE) ADAPTED FROM S. YOKOYAMA

* The American Genetic Association met from 11 to 13 June in State College, Pennsylvania.

rhodopsins had nudged their peak absorbencies to the shorter wavelengths, Yokoyama and his colleagues compared the sequences of the coelacanth rhodopsins to those of other fish that live closer to the ocean surface. They found two amino acid changes in each of the two coelacanth rhodopsins that seemed likely to underlie the shift in wavelength absorbencies.

The researchers went on to test their prediction by introducing mutations into the coelacanth rhodopsin genes to change those amino acids, one at a time, to those found in the typical fish rhodopsin. Measurement of the wavelength sensitivities of the normal and altered coelacanth rhodopsins told the researchers that their predictions were correct. Each mutation contributed additively to shifting the coelacanth opsins from their native sensitivity peaks—a wavelength of 485 nanometers for one and 478 nanometers for the other—to longer wavelengths. The coelacanth's distinctive amino acids apparently alter the fit between the opsin and the chromophore, which starts to vibrate when hit by light, and therefore affect the chromophore's responsiveness to particular wavelengths. Together, Yokoyama says, the amino acid changes enable the coelacanth "to see the limited range of color available in that environment."

After comparing the rhodopsin genes in coelacanths and other fish with the same genes in birds and reptiles, Yokoyama thinks that one of the changes in one gene occurred after coelacanths and other fish went their separate evolutionary ways but before coelacanths and legged animals split up. That same change—replacement of a glutamic acid by a glutamine—occurred independently in the second gene after the coelacanth diverged from this ancestor. Each coelacanth rhodopsin then underwent a second change; in one case an alanine became a serine and in the other, a methionine became a leucine.

More recently, Yokoyama and his graduate student F. Bernhard Radlwimmer have laid the groundwork for more studies of how various opsins have specialized in the course of evolution. Previous work by Yokoyama and others pointed to five sites in the opsins where amino acid changes affect the absorbencies of the so-called red and green pigments used to detect middle wavelengths. He and Radlwimmer have now cloned and sequenced the genes for those opsins in the cat, horse, gray squirrel, white-tailed deer, and guinea pig and, based on which amino acids they contain at those sites, estimated the light-sensing properties of each protein.

Yokoyama and Radlwimmer then made the pigments in cultured cells and tested their predictions. "The additive effects of these amino acid changes fully explain virtually all the [peak light-absorption] values," says Yokoyama. "We can predict what kind of vision [an animal] will have based on the [amino acids] at these five sites." Indeed, says Hiroshi Akashi, an evolutionary biologist at the University of Kansas, Lawrence, "[the] work beautifully demonstrates that a few sites within proteins can account for most differences in the wavelength absorbence in visual pigments." (These results will appear this fall in *Genetics*.) At this point, however, it's less clear how these changes improve each species' ability to see in its particular environment.

For years, Dean says, too many evolutionary biologists have used gene sequence differences simply to assess the evolutionary distance between species, rather than trying to tie them to function. But Yokoyama, he notes, is in a small band of researchers who have taken the next step and begun to study evolution's course from a molecular perspective as well. Dean hopes the approach will spread, because tracing adaptation to molecular changes "allows evolutionary hypotheses to be tested far more rigorously than had been imagined." —ELIZABETH PENNISI

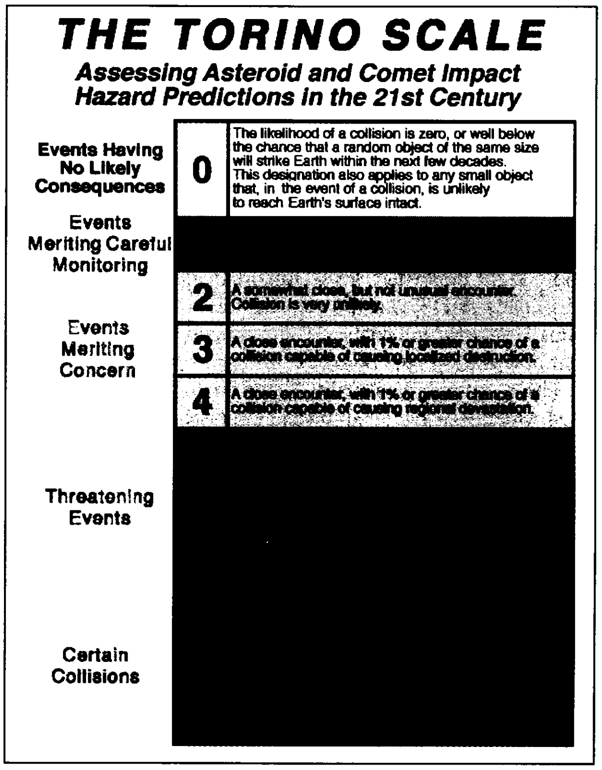
IMPACT HAZARDS

And Now, the Asteroid Forecast ...

Astronomers have devised a scale to rate the danger posed by asteroids headed for Earth, comparable to the Richter scale of earthquake fame. The so-called Torino scale, which ranges from 0 (no collision) to 10 (certain collision causing Earth-wide devastation), was developed by Richard Binzel of the Massachusetts Institute of Technology and presented to colleagues during a June workshop in Turin (Torino), Italy. The International Astronomical Union endorsed it last week.

The topic of asteroids is "prone to sensationalism," says Binzel. Twice in recent years media hype erupted after astronomers discovered a rock that had a remote possibility of slamming into Earth (*Science*, 20 March 1998, p. 1843, and 23 April 1999, p. 565). "It's very hard to communicate extremely low probabilities to the general public," says Binzel. "The new scale gives us a common lexicon."

The scale, which Binzel had been working on since 1994, takes into account the chances that an asteroid will hit as well as its size and speed relative to Earth. Torino scale values of 8, 9, and 10 refer to certain collisions, with local, regional, and global consequences, respectively. But "the average citizen shouldn't be concerned about an asteroid with a Torino value of 1," says Binzel. The two recently discovered asteroids both would have been rated 1 when they were first discovered, but subsequent observations would have placed them firmly in the 0 category. Binzel says he was advised by science writers Kelly Beatty of *Sky & Telescope* and David Chandler of *The Boston Globe*. "In formulating the scale, we tried to be sociologists as well as scientists," he says.



Carl Pilcher of NASA's Office of Space Science calls the Torino scale "a major advance in our ability to explain the hazard posed by a particular [object]." But will astronomers adopt the new scale? "This will have to sink in a little bit," says Tom Gehrels of the Lunar and Planetary Laboratory of the University of Arizona, who heads one of the projects searching for near-Earth objects. But he adds, "I think we ought to use it." —GOVERT SCHILLING

Govert Schilling is a writer in the Netherlands.

CREDIT: R. BINZEL