NuSTAR in the Sky with X Rays

HEFT hangs from a crane while waiting for its balloon to go up at the National Scientific Balloon Facility at Ft. Sumner, New Mexico. The sphere over the crane's left wheel houses the detectors, while the mirror is at the top of the central tube pointing upward and to the right.

If all goes well, an innovative telescope should be orbiting Earth by 2009 and taking the first well-focused, high-energy X-ray pictures of matter falling into black holes and shooting out of exploding stars. Not only will the telescope be 1,000 times more capable of finding black holes than anything previously launched into space, it will also give us an unprecedented look at the origins of the heavy elements we're all made of. Named the Nuclear Spectroscopic Telescope Array—or NuSTAR, for short—the project has been approved for detailed study as part of NASA's Small Explorer program (SMEX), which seeks out new technologies and new proposals for space missions that can be launched at low cost. NuSTAR will go through a confirmation review early next year to decide if it is ready to proceed.

A key high-altitude-balloon test on May 18 went well, says Fiona Harrison, an associate professor of physics at Caltech and NuSTAR's principal investigator. "We got lots of good data—images of the background and of cosmic sources—that demonstrate the NuSTAR concept." The balloon spent 20 hours in the stratosphere at 128,000 feet. The balloon's instrument, called HEFT (for High-Energy Focusing Telescope), returned sharp pictures at "hard X-ray" wavelengths—in this case, about 20 to 100 kilo electron volts—the first ever from high altitudes. In fact, the HEFT images are superior to existing satellite data at these energies. And NuSTAR will do even better, Harrison explains, because it will get above *all* of Earth's atmosphere. NuSTAR will observe at an altitude of about 550 kilometers for at least three years.

Hard X rays penetrate the gas and dust of galaxies much better than the "soft," lower-energy X rays observed by NuSTAR's forerunners. But hard X rays are very difficult to focus. They aren't bent by lenses, and they can only be efficiently reflected at very glancing angles. So HEFT and NuSTAR use specially coated surfaces placed nearly edge-on to the incoming X rays, which hit at a shallow angle and are gently deflected. The mirrors are nested like Russian dolls, increasing the number of photons focused. NuSTAR will have three sets of them, each composed of an amazing 150 nested paraboloids, called "shells," which are in turn made of 24 smaller pieces. (The coatings consist of hundreds of alternating layers of tungsten and silicon, each only a few atoms thick. Building these shells and the cadmium-zinc-telluride photon detectors has required groundbreaking work in a number of Caltech labs.) The X rays grazing off the mirrors come to a focus about 10 meters away, and the mirrors and detectors must be held rock-steady to prevent blurring. So NuSTAR's mirrors will be on the end of an accordion-like expandable mast that is only 45 centimeters long when

Hollywood Boulevard became the Scientists' Walk of Fame for a few hours on the morning of May 4, when more than 500 stars were relabeled as the class of '05's senior prank. Feynman got a star, of course, as did Galileo, Newton, Einstein, Stephen Hawking, Marie Curie, and a host of others who, alas, aren't quite such household names. Professor of Chemical Physics Aron Kuppermann, who does quantum-mechanical modeling of chemical reactions, got a choice spot across the street from Mann's (formerly Grauman's) Chinese Theater and its famed courtyard of footprints in cement.

retracted.

NuSTAR has three main objectives. One is to count black holes of all sizes and measure the "accretion rate" at which material has fallen into them over time. The second is to trace how elements are formed in supernova explosions and then mixed in the interstellar medium, which is the space between stars. And finally, NuSTAR will study the highly energetic jets that stream out of certain black holes at nearly the speed of light—an enigmatic but powerful phenomenon.

The Jet Propulsion Laboratory (managed by Caltech for NASA), Columbia University, the Stanford Linear Accelerator (SLAC), the Lawrence Livermore National Laboratory, the University of California at Santa Cruz, and the Danish Space Research Institute are also participating in the project. The spacecraft will be built by General Dynamics C4 Systems. JPL is, among other things, managing the mission and overseeing the production of the mast, which is based on the design used in the Lab's hugely successful Shuttle Radar Topography mission. The Small Explorer program is designed to provide frequent access to space with small-to-midsized spacecraft for physics and astronomy. NASA has launched six SMEX missions since 1992, including the Galaxy Evolution Explorer, launched in April 2003 and led by Professor of Physics Chris Martin (see *E&S* 2004, No. 2). □

Who Do You Trust?

The question may seem distinctly human—and limited only to "quality" humans, at that—but it turns out that we learn to trust in pretty much the same way that insects learn to expect food rewards. In other words, it's a lot more primitive than you might think. Furthermore, our biological roots make us reasonably trustworthy most of the time. In a neuroscientific milestone, experimenters at Caltech and the Baylor College of Medicine have, for the first time, simultaneously scanned the brains of subjects playing an economic game and building a trusting relationship.

The researchers placed volunteers in functional magnetic resonance imaging (fMRI) machines in Pasadena and Houston, respectively. Neither volunteer knew the other, and the two would play an economic game in which trustworthiness had to be balanced with the profit motive. Meanwhile, their brain activity was monitored through a new technique called "hyperscanning" brain imaging. The fMRI picks up evidence of a rush of blood to a specific part of the brain, which indicates that that region is more active.

According to Steve Quartz, associate professor of philosophy and director of the Social Cognitive Neuroscience Laboratory at Caltech, who led the Caltech effort, the results show that trust involves a region of the brain known as the head of the caudate nucleus. But the key finding was that trust tended to shift backward in time as the game progressed. In other words, the expectation of a reward was intimately involved in each subject's assessment of the other's trustworthiness, and that the recipient tended to become more trusting prior to the reward coming—provided, of course, that there was no backstabbing.

In the game, one player (the "investor") is given $20 and must choose to hold on to it or give some or all of it to the other player (the "trustee") 1,500 miles away. Any money the trustee receives is tripled, and the trustee can then give some or all of it back to the investor. In a perfect world, the investor would give the trustee the entire $20, which becomes $60, and the trustee would return $30 to the investor. But greed can make the trustee keep all the profit, or stinginess or lack of trust might persuade the investor to keep the original stake.

The researchers found that trust is delayed in the early rounds of the game (there are 10 in all), and that once the players begin determining the costs and benefits, the rewards get anticipated before they're bestowed. Players soon start showing activity in the head of the caudate nucleus that demonstrates an "intention to trust." Once the players know each other by reputation, they begin showing their intentions to trust about 14 seconds earlier than in the early rounds of the game.

"Neoclassical economics starts with the assumption that rational self-interest is the motivator of all our economic behavior," says Quartz. "The further assumption is that you can only get trust if you penalize people for non-cooperation, but these results show that you can build trust through social interaction, and question the traditional model of economic man." "They also show that you can trust people for a fair amount of time, which contradicts the assumptions of classical economics," adds Colin Camerer, the Axline Professor of Business Economics at Caltech and the other Caltech faculty author of the paper.

This is good news, Quartz explains, because trustworthiness decreases the incidental costs of doing business: a trusting society needs fewer laws to encumber it, fewer attorneys to ensure that documents are airtight, and so on. "It's like a deal on a handshake. You don't have to pay a bunch of lawyers to write up what you do at every step. Trust is of great economic importance, from everyday interpersonal interactions all the way up to the economic prosperity of a country, where trust is thought of in terms of social capital."

Behaviorally, the findings are similar to classical conditioning experiments. Just as a person is rewarded for trusting a trustworthy person—and begins trusting that person sooner—so, too, does a lab animal begin anticipating a reward for slobbering when a buzzer sounds, pecking a mirror, or extending the proboscis when a certain odor is smelled (see page 47). "This is another striking demonstration of the brain re-using ancient centers for new purposes. That trust rides on top of the basic reward centers of the brain is something we had never anticipated and demonstrates how surprising brain imaging can be," Quartz notes.

And, finally, the research could help understand the neurology of autism and schizophrenia. "The inability to predict others' behavior is a key facet of many mental disorders. These results may ultimately suggest new treatments," says Quartz.

The paper appeared in the April 1 issue of *Science*. The other authors are Brooks King-Casas, Damon Tomlin, and P. Read Montague (the lead author), all of the Baylor College of Medicine, and graduate student Cedric Anen of Caltech. □—*RT*

It's been a good season for pranks. A bunch of enterprising Techers flew east to attend That Other Institute of Technology's prefrosh weekend, where they distributed these shirts—packaged individually in plastic and neatly folded so that only the front logo was visible. The shirts are now on sale at the bookstore—go to www.bookstore.caltech.edu.

Erratum

The first paragraph of "The Caltech–Chile Connection" (*E&S*, 2004, No. 4) said that the cosmic microwave background radiation "was emitted just 400,000 years after the Big Bang (the equivalent of about 45 minutes after conception when compared to a human life)." A alert reader e-mailed:

> "I would expect more like 1,000 minutes (400,000/15 × 10^9 × no. of minutes for a 71-year-old).
> Yours truly, Rodger [Baier] (a 75-year-old chemist from the class of '52)"

To which Tony Readhead, the Rawn Professor of Astronomy and principal investigator for the Cosmic Background Imager, replies:

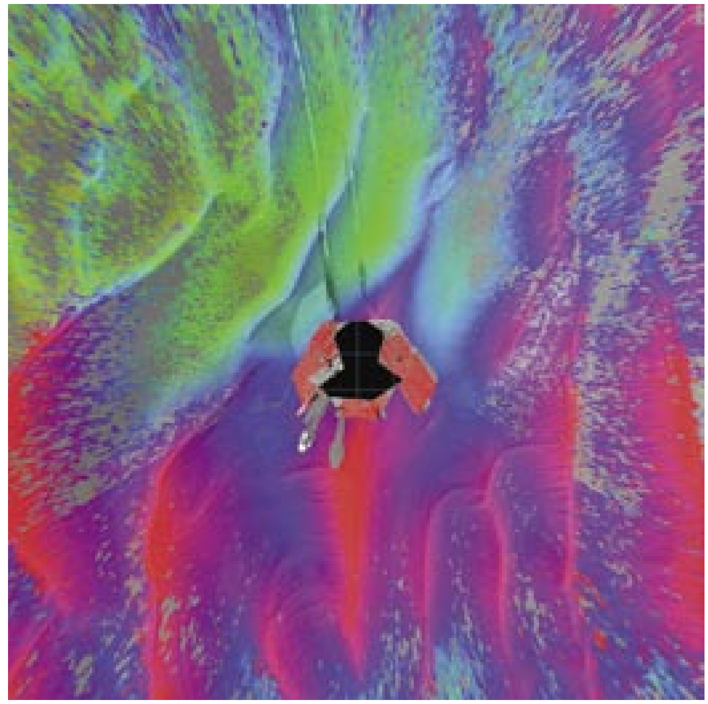
> "Sorry to say that I screwed up.
> The 3 hours was for a 14-year-old—and that was correct.
> I meant to change it to the relevant time for a 70-year-old—i.e. a change of × 5 instead of which I divided by 5."

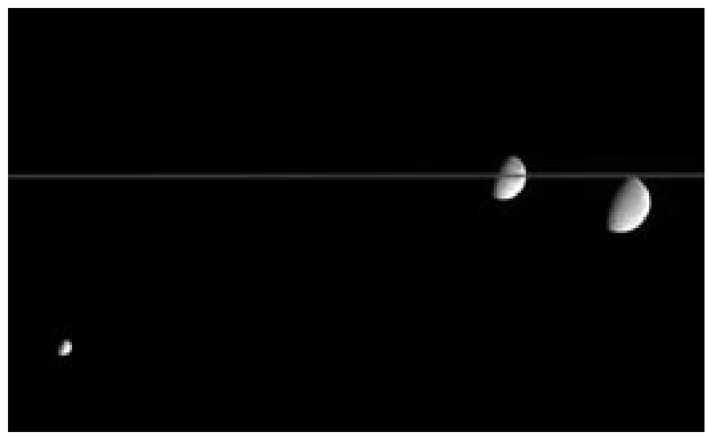
There may be hope for the rest of us yet! □—*DS*

E&S Editor Retires

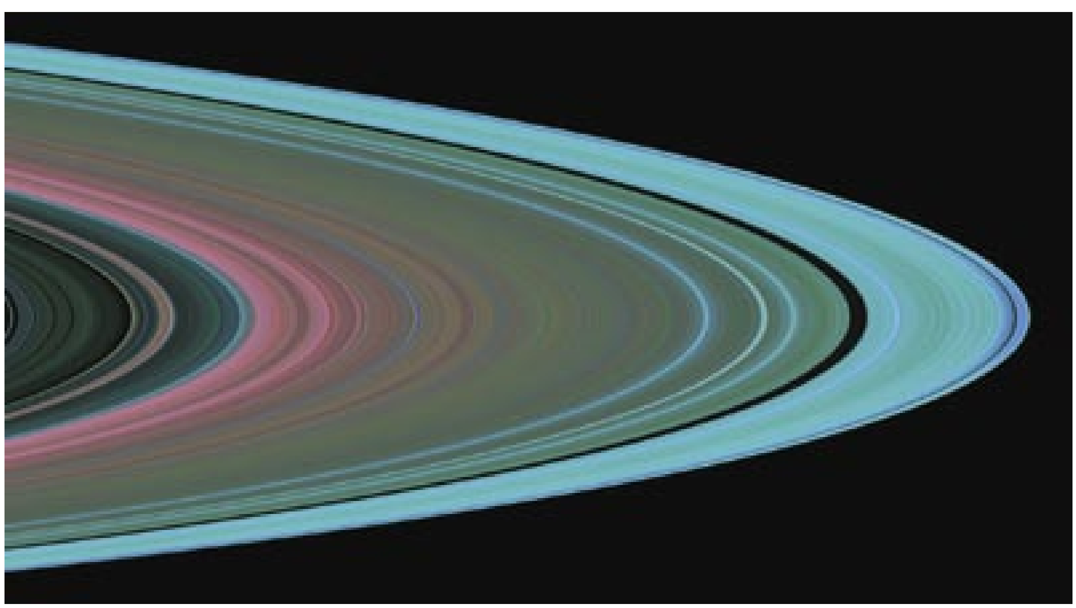
Jane Dietrich, editor of *Engineering & Science* since 1984, has called it a career. Dietrich joined Caltech as the writer for *E&S* in 1979, back when the magazine was produced using typewriters and paste-up boards, and color was a rare and expensive commodity seen only on the cover. As director of periodicals, she led *E&S*, *Caltech News*, and the staff newspaper, *On Campus*, into the age of desktop publishing—long before it was known by that name—and onto the Internet.

Doug Smith, her successor, has been with *E&S* for 18 years, the last 13 as managing editor. He expects that by the time he retires, *E&S* will be beamed directly into readers' heads via neural transceivers. □—*DS*





Above, right: Good news and bad news from Mars. The good news is that the winds have cleaned off the rovers' solar panels, restoring them to nearly full power. The bad news is that Opportunity is stuck hub-deep in a small dune on Meridiani Planum. JPL engineers working to free their robot made this plot of relative elevations, with green being the lowest and red being about 70 centimeters higher. Right: Cassini snapped this shot of, from left, Mimas, Dione, and Rhea as the spacecraft crossed the plane of Saturn's rings. The bright F ring can be seen above and below the darker A and B rings in front of it.



Right: Cassini's orbit was designed to allow radio signals to be sent back to Earth through the rings—a so-called occultation experiment—in order to measure the ring particles' size and distribution. In this rendering, red indicates regions where the particles are greater than five centimeters in diameter, and green and blue show where there are particles smaller than five centimeters and one centimeter, respectively.