UNBOUND

Ultra-High-Energy Cosmic Rays – Fierce Particles from Deep Space

BRIAN CONNOLLY IS NOT YOUR TYPICAL PARTICLE PHYSICIST. He often works in wide-open meadows on moonless nights, surrounded by cows. At the end of his shifts, he shakes his clothing to get rid of stray tarantulas and black widow spiders. But the animal adventures are worth it: Connolly is chasing the wildest particles in the universe, called ultra-high-energy cosmic rays.

Connolly and his colleagues from Columbia University are helping to build the world's largest detector of these rays in the high plains of Argentina. The observatory looks rather strange, with 24 ultraviolet telescopes and 1,600 water tanks spread across an area the size of Rhode Island. But the array is designed to catch the rarest bits of matter that space hurls at us, with a ferocity that makes the atom-smashing machines of physicists look like BB guns.

Indeed, ultra-high-energy cosmic rays carry up to 100 million times more energy than particles in the biggest physics colliders on Earth. They pack as much punch into a single subatomic speck as a tennis ball served by Andy Roddick – or a brick dropped from shoulder height onto your foot.

Yet scientists don't know where these furious particles are born. "It's one of the biggest unsolved problems in astrophysics," says Stefan Westerhoff of Columbia. "We have no idea how they are accelerated." The possibilities range from explosions that spawn black holes to galaxies crashing together, or even exotic events beyond the pale of today's science. Within a few years, the Argentina observatory may provide the answer.

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The mystery began in 1912, when Austrian physicist Victor Hess first discovered cosmic radiation by flying in a hot air balloon with a particle gauge. Scientists later learned that most cosmic rays are simply fast-moving nuclei of the most common atoms in the universe: hydrogen and helium. When these atomic fragments slam into Earth's atmosphere at nearly the speed of light, they spark "air showers" of millions of particles that constantly rain down upon us.

Modern instruments have shown that most low-energy cosmic rays stream from our sun and other stars. Dying stars called supernovas spew faster particles. But the highest-energy ones are thousands of times more powerful. They're also exceedingly rare. An ultra-high-energy cosmic ray might strike each square kilometer of Earth's surface just once per century. Trying to detect these elusive particles and trace their origins is the focus of Connolly and Westerhoff's research.

The physicists used to work with hundreds of

A new array of water tanks in Argentina may detect cosmic rays from colliding galaxies (top).

PIERRE AUGER OBSERVATORY

IMAGE TOP: GALAXIES: NASA/STSCI/ACS SCIENCE TEAM

scientists on huge collider projects. Cosmic rays were a refreshing change, says Westerhoff. The link with astronomy was intriguing, and the research teams are far smaller. "It's still a field where you can have some personal impact," he says.

The two joined other Columbia physicists on a project in Utah called High-Resolution Fly's Eye, or HiRes. On clear moonless nights, the segmented mirrors of the HiRes telescopes watch for flashes of ultraviolet light about 10 kilometers high. The narrow streaks of light come from nitrogen atoms in the air, set aglow by the intense showers of particles triggered by cosmic rays.

A different experiment in Japan, called AGASA, also tracked ultra-high-energy cosmic rays during the last decade. However, AGASA spotted the events on the ground, rather than in the air. The team used special detectors made of plastic to register the impacts of cosmic-ray air showers throughout a long river valley.

Both HiRes and AGASA tracked hundreds of extremely energetic events all over the sky. But after years of operation, their results didn't quite agree. For instance, it's not clear how powerful the rays can grow. HiRes scientists think cosmic rays get drained of energy as they travel through the faint glow of space itself, like swimmers slowing down as water drags on their bodies. In contrast, the Japanese results suggest that many cosmic rays smash beyond this natural speed limit. If so, the rays might point to brand-new physical processes that no current theory describes.

PIERRE AUGER OBSERVATORY

The Andes rise beyond the Pierre Auger Observatory.

The new facility in Argentina, called the Pierre Auger Observatory, may settle this dispute. Named for the French physicist who discovered cosmic ray air showers in 1936, Auger ("oh-ZHAY") spreads across 3,000 square kilometers of Argentine pampas, or grassland. "It's a huge, vast area. It's quite beautiful," says Westerhoff. The snow-covered peaks of the Andes soar in the distance. Physicists like traveling there for another reason, Westerhoff notes: "The food and the wine are exceptionally good."

Auger's 1,600 water tanks each contain 12 tons of purified water inside a light-tight bladder. When particles from an air shower pierce into the water, shock waves create blips of blue light that detectors relay to the central station. The tanks cover so much ground that Auger can see the rarest, biggest showers that smaller facilities would miss.

Moreover, Auger has 24 telescopes that watch the skies for ultraviolet flashes overhead. The idea is to catch the most powerful cosmic rays both in the air and on the ground – combining the strengths of HiRes and AGASA. That gives scientists a more reliable gauge of how much energy the rays contain and where they came from. The Columbia group helps monitor the sky conditions on every dark night.

Water vapor or dust can weaken the signal seen by the telescopes, like fog that shrouds a lighthouse beacon. That would skew the calculation of a particle's energy. To account for this, the scientists shoot

NEW YORK SCHOOLS CATCH SOME RAYS

NEW YORK CITY OVERFLOWS WITH WATER TANKS. EVERY BUILDING TALLER THAN 6 stories has to have one. Glennys Farrar of New York University wants to use hundreds of these tanks to spot energetic cosmic rays – and she's enlisting students to help make it happen.

This summer, Farrar and students from Hunter and Stuyvesant High Schools, the Cooper Union college, and retired volunteers converted a reserve water tank at NYU into a cosmic-ray bucket. Retrofitted to be dark inside, the tank contains detectors, to see cosmic-ray flashes, and filters to keep the water clear.

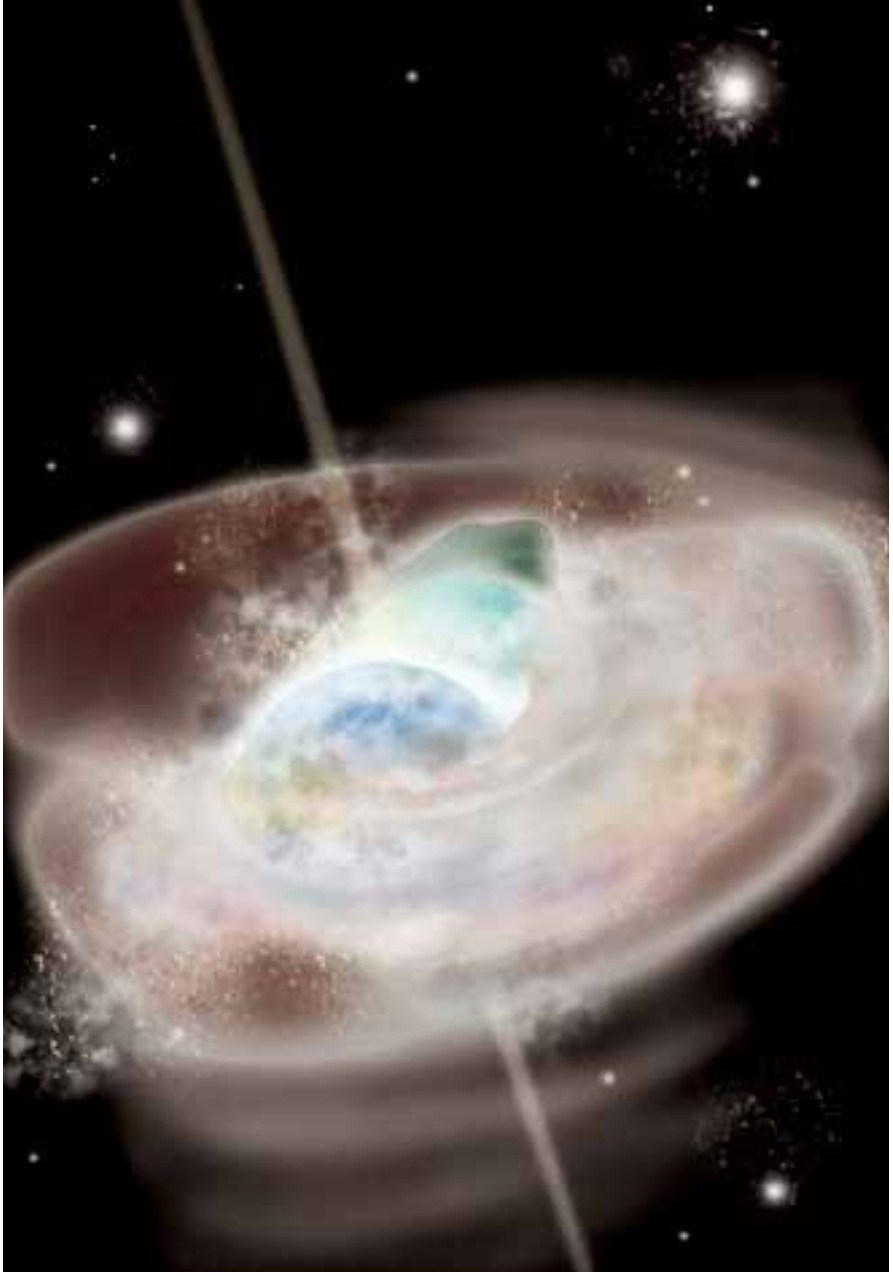
Farrar plans to request funding from the National Science Foundation to create a small array of a few dozen such tanks, concentrated on Manhattan. Ultimately, she envisions 1,000 wired tanks spread into the five New York boroughs and beyond.

At the same time, physics classes in public schools would have plastic detectors that emit tiny charges every time high-energy particles zip through. Internet connections would link the plastic and water-tank detectors into an urban cosmic-ray experiment – potentially, one of the world's most sensitive.

NEW YORK SCHOOLS COSMIC PARTICLE TELESCOPE/NYU

Physicists convert a water tank at New York University to detect particles from space.

When Farrar led a recent workshop on cosmic rays for teachers and students at 10 schools, she found that the science was a powerful draw. "We can do a cutting-edge experiment and have a great impact on kids," she says. "If they can participate in a major discovery, it would really capture their interest."



NASA/SONOMA STATE UNIVERSITY/AURORE SIMONNET

Merging neutron stars (artist's conception) may blaze with energetic cosmic rays.

lasers into the sky and measure the scattered light that returns. It's an all-night task. "The weather can change dramatically in half an hour, from completely cloudy to completely clear," says Connolly. "If we see an air shower, we need to know whether it passed through a cloud."

By summer 2005, the Auger team had built about half of the array and was preparing to announce its first results. Soon, physicists hope to resolve some basic puzzles. For example, there are clues that some ultra-high-energy cosmic rays come from known sources in space, such as powerful galaxies called "blazars." Astronomers believe that gigantic black holes sit at the centers of these galaxies. As matter spirals into the black holes, gas gets so hot that it erupts into narrow geysers of energy. If one of these jets happens to point our way, we see bright flares of light and, possibly, occasional spurts of cosmic rays.

For now, the link between cosmic rays and blazars is a "weak association," says Westerhoff. But the greater number of cosmic rays seen by Auger should reveal whether the connection is real.

Theorist Glennys Farrar of New York University also is on the trail of potential sources. Recently, Farrar analyzed data from HiRes and AGASA. She found a cluster of five ultra-high-energy cosmic rays on the sky. In that same area, two groups of galaxies are colliding violently about 600 million light-years from Earth. Farrar sees signs that the particles all sparked into life within one of the turbulent galaxies at about the same time. "Whatever created them was probably a cataclysmic event, rather than an ongoing process," she says. Her favored candidate is a gamma-ray burst, the death of a giant star in an explosion that instantly forms a new black hole.

Many other physicists think the cluster of cosmic rays could have happened by chance. If the most powerful rays do indeed come from random directions, then scientists may need to resort to bizarre explanations for them. One popular idea is that the Big Bang created extremely heavy particles that drift invisibly through space. Now, billions of years later, some of these unstable particles are finally decaying in a blaze of radiation. Putting such wild ideas to the test makes the field fun, says Farrar: "We may end up learning that a variety of things make ultra-high-energy cosmic rays."

Physicists from 15 nations are collaborating on Auger, so the challenge transcends borders and cultures. Even the natives of the Argentine pampas are excited, Connolly says. "No one speaks English, and there's an invasion of foreigners from all over the world onto their land," he reports. "But one night, the entire town turned out the lights to gaze at the sky with telescopes. Our experiment has made them want to look up at the stars."

–Robert Irion

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For more information about ultra-high-energy cosmic rays, download the "Cosmic Extremes" brochure from the Columbia University physics department at http://hires.phys.columbia.edu/papers/CosmicExtremes.pdf (2.3 MB pdf). The home page of the Pierre Auger Observatory in Argentina is www.auger.org.