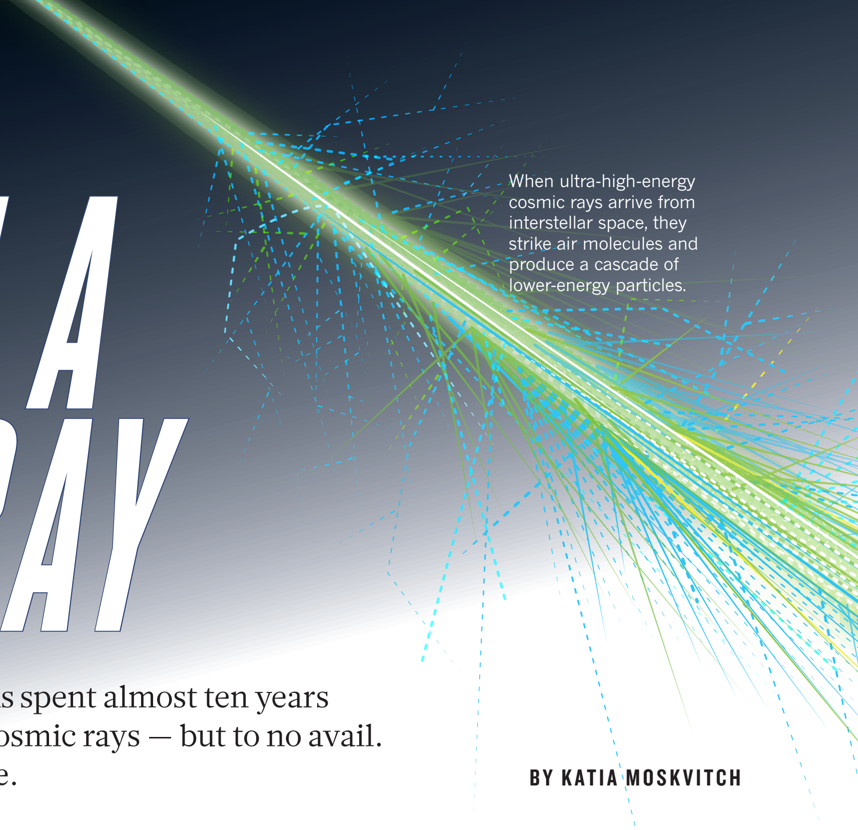
# TO CATCH A COSMIC RAY



When ultra-high-energy cosmic rays arrive from interstellar space, they strike air molecules and produce a cascade of lower-energy particles.

**The Pierre Auger Observatory in Argentina has spent almost ten years looking for the source of ultra-high-energy cosmic rays — but to no avail. Now the observatory faces an uncertain future.**

BY KATIA MOSKVITCH

The tank looks oddly out of place here on the windy Pampas of western Argentina. Surrounded by yellow grass and spiky thorn bushes, the chest-high plastic cylinder could be some kind of storage container — were it not for the bird-spattered solar panels and antennas on top.

More tanks can be seen in the distance, illuminated by a crimson Sun dropping behind the far-off Andes. "Some locals think that the tanks influence the weather: they make it rain or snow, or make a dry season," says Anselmo Francisco Jake, the farmer who owns this stretch of land. "But I know they don't. I know they catch cosmic rays."

Jake is right. There are 1,600 of these tanks, spaced over a 3,000-square-kilometre expanse that could fit all of Luxembourg with room to spare. Together they comprise the Pierre Auger Observatory: a US$53-million experiment to reveal the mysterious origins of ultra-high-energy cosmic rays, the most energetic subatomic particles known to exist.

But for all its size, the array has fallen short. After almost ten years of hunting, it has observed dozens of ultra-high-energy cosmic rays, but has not managed to solve the mystery of where they come from. As a detector, "the device worked twice as well as we expected", says project co-founder James Cronin, a retired astrophysicist at the University of Chicago in Illinois. But the particles seem to be coming from all over the sky, with too little clustering for researchers to pinpoint the sources. "It's up to nature with experiments like this one," he says.

Now, the Auger team is putting its hopes on a proposed upgrade that might settle the question by improving Auger's resolution considerably. Five designs are being evaluated internally by a committee of Auger physicists, who are expected to present their final selection to the array's many funding agencies in November. The trouble is, there is a sixth option, too. "In the worst-case scenario, and I don't want to think about it, we may get shut down," says Auger's deputy project manager, physicist Ingo Allekotte.

An upgrade would require an investment of roughly $15 million, and some argue that the money would be put to better use elsewhere. "Although it was worth building Auger, it was a gamble that unfortunately didn't yield much new understanding," says Eric Adelberger, a physicist at the University of Washington in Seattle. "Cosmic-ray physics has delivered very few surprises and progress is terribly slow. Maybe it is time to move on."

> **"It's up to nature with experiments like this one."**

That would be a blow to science — and to Argentina, say Auger's supporters. These flagship projects do more than just conduct research, says Pablo Mininni, head of the physics department at the University of Buenos Aires. They also raise awareness of physics and draw young people into the field. "Such a big project deserves some continuity," he says.

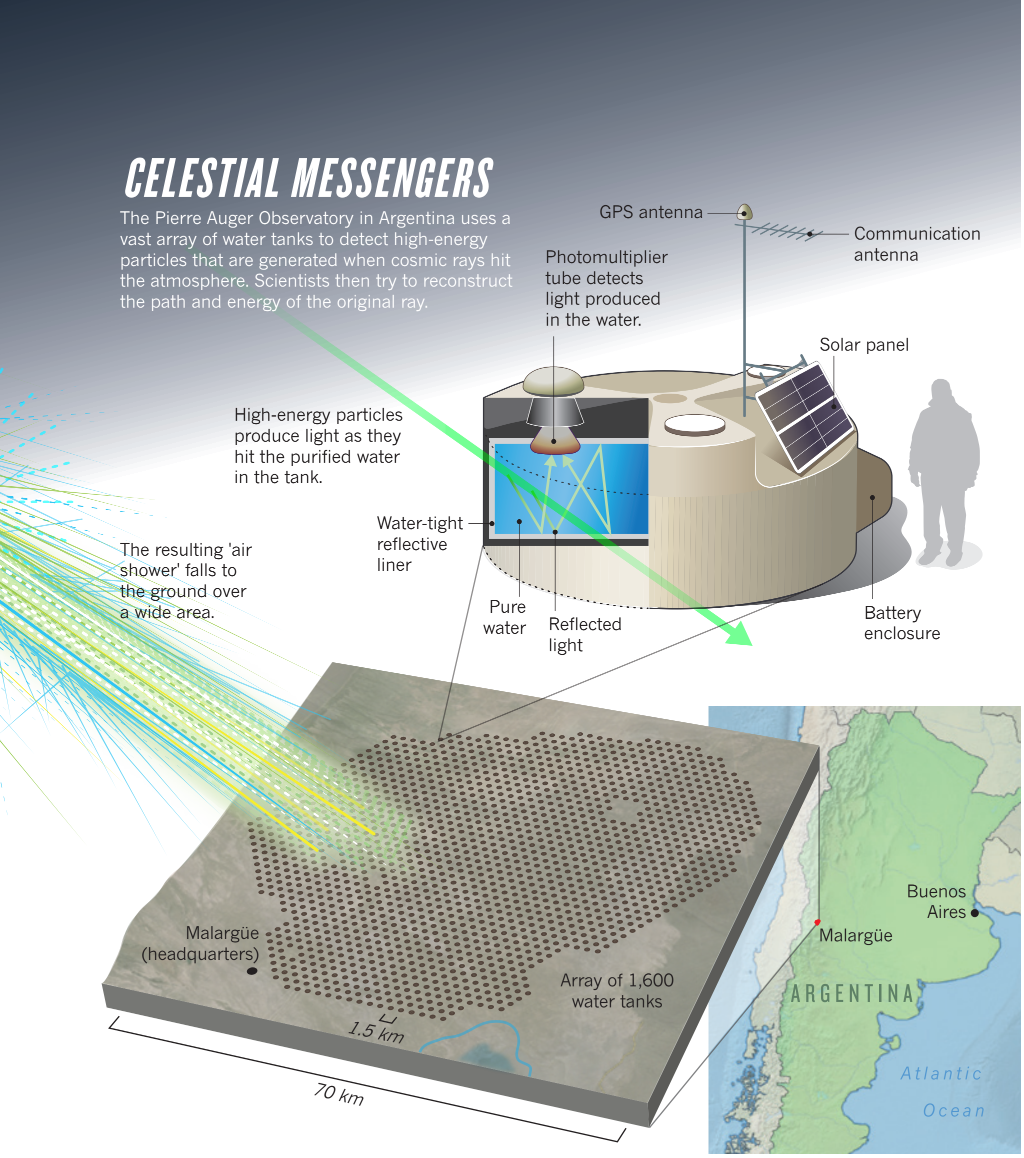
Physicists have known for more than a century that Earth is continually bombarded by charged particles from space — many of which have energies that are astonishing even by particle-physics standards. It is not uncommon for cosmic rays to have hundreds or thousands of times the 7 trillion electron volts ($10^{12}$ eV) soon to be achieved by the most powerful human-made particle accelerator, the Large Hadron Collider (LHC) near Geneva in Switzerland.

Most of these particles are now thought to be protons and other light nuclei originating far outside the Solar System, probably in cataclysmic stellar explosions known as supernovas. But on very rare occasions, cosmic rays have hit Earth's atmosphere at energies of $10^{18}$ eV or more. The most energetic example on record — the 'Oh-My-God particle' detected[1] on 15 October 1991 in the skies above Utah — had $3 \times 10^{20}$ eV, about 40 million times that of the LHC. And therein lies a mystery: calculations suggest that the expanding shock wave of a supernova detonation cannot accelerate charged particles beyond about $10^{17}$ eV. No one knows what physical process could accelerate particles to higher energies — or even what those particles might be (see *Nature* **448,** 8–9; 2007).

## RULE-BREAKERS

In 1992, Cronin, who shared the 1980 Nobel Prize in Physics for his work on particle interactions, decided to find out. He, Alan Watson of the University of Leeds, UK, and Murat Boratav of Pierre and Marie Curie University in Paris, set out to build an observatory that — they hoped — could detect enough ultra-high-energy cosmic rays to answer those questions.

Their sprawling, 1,600-detector design reflected two fundamental facts about their quarry. The first is that the rays are exceedingly rare. Although their low-energy cousins come in at roughly a few particles per square centimetre per second, the rates dive




**CELESTIAL MESSENGERS**

The Pierre Auger Observatory in Argentina uses a vast array of water tanks to detect high-energy particles that are generated when cosmic rays hit the atmosphere. Scientists then try to reconstruct the path and energy of the original ray.

precipitously as the energy increases. Above $10^{20}$ eV, the cosmic-ray flux is less than one particle per square kilometre per century. So the more detectors the researchers could deploy, the better their chances would be of catching one.

The second fact is that 'primary' cosmic rays — those that are coming in from interstellar space — never reach the ground. Instead, they smash into an air molecule high in the atmosphere, producing a blast of photons, electrons, positrons, muons and other collision products that then slam into other air molecules. The result is an 'air shower': a cascade of lower-energy particles that collectively follow along the track of the original cosmic ray. And that calls for detectors over a very wide area, in the hope that the devices could register enough of the air-shower particles as they hit the ground to reconstruct the energy and direction of the original particle (see 'Celestial messengers'). To help in the reconstruction, the physicists also planned to surrounded the site with four clusters of fluorescence telescopes to scan the skies over the array, mapping the faint streaks of blue and ultraviolet light that the air-shower particles produce as they rip through the atmosphere.

Naming their observatory after Pierre Auger, the French physicist who discovered air showers in 1938, the three scientists started going from country to country knocking on doors. They gathered a cadre of high-level physicists from around the world who wanted to join them. And those physicists, in turn, used their connections to get funding from their own governments. In short order, the United States agreed to help, as did Italy, Germany, France, Argentina and several other countries.

At the same time, the Auger team was looking at potential sites in South Africa, Australia and South America — places that met their need for lots and lots of empty, flat land with clear skies above. Nelson Mandela dearly wanted the observatory to be based in South Africa. But the Auger team judged that the nation did not have a strong-enough community of physicists to support the project.

The Australian site had a different drawback: it was on land controlled by the military, so collaborators from certain countries might not be able to work there.

So in November 1995, Cronin, Watson and Boratav announced that the observatory would be built in Pampa Amarilla, a plain some 1,400 metres above sea level. Except for Malargüe, a mining town of 23,000 people just to the southwest, the site was as empty as the Auger team could wish. Better still, Argentina's then-president, Carlos Menem, was so excited by the idea of his country hosting an international science project that he promised to support it with the equivalent of US$10 million in Argentinian pesos. The province of Mendoza, where the site is located, agreed to contribute another $5 million.

This largesse would prove to be a mixed blessing: in 2001, just as construction was getting under way, Argentina experienced its biggest economic crisis and government default in history. The peso instantly lost two-thirds of its value, leaving the researchers to scramble for funding from other sources to keep construction on schedule. It was one of Auger's biggest setbacks, says Cronin. Another came in 2010, when US funding agencies declined the researchers' request to build a sister observatory in Colorado, which would have allowed them to look for the ultra-high-energy cosmic-ray sources across the entire sky instead of just the Southern Hemisphere.

## AIR SHOWERS

Still, the first 154 detectors of the Auger observatory were able to start collecting data on 1 January 2004, with the rest of the detectors being deployed in stages until the array was completed in 2008. Each of the plastic tanks is filled with 12,000 litres of purified water, which produces a streak of light when an air-shower particle passes through, and is lined with phototubes that can measure that light. The tank's antennas transmit the data to the observatory's headquarters in Malargüe, where they are sent out for analysis to some 350 researchers around the world.

Their first decade of data-taking has yielded a number of provocative results, including hints that many of the highest-energy rays are actually heavy nuclei such as that of iron, instead of the much more common protons[2]. "It was a surprising result that nobody had thought about," says Auger spokesman Karl-Heinz Kampert, a physicist at the University of Wuppertal in Germany. And if true, it might have something important to say about the mysterious acceleration mechanism — although no one is quite sure what. It also threatened to undermine Auger's central quest: heavy nuclei tend to be more strongly deflected by intergalactic magnetic fields than protons are, and that could randomize their direction and make it impossible to trace the rays back to their sources.

That concern seemed to have been put to rest in 2007. Working with three-and-a-half years of data gleaned from 27 rays, Auger researchers reported that the rays seemed to preferentially come from points in the sky occupied by supermassive black holes in nearby galaxies[3]. The implication was that the particles were being accelerated to their ultra-high energies by some mechanism associated with the giant black holes. The announcement generated a media frenzy, with reporters claiming that the mystery of the origin of cosmic rays had been solved at last.

KATIA MOSKVITCH

The Pierre Auger Observatory's detectors sit incongruously in western Argentina's yellow prairie.

But it had not. As the years went on and as the data accumulated, the correlations got weaker and weaker. Eventually, the researchers had to admit that they could not unambiguously identify any sources[4]. Maybe those random intergalactic fields were muddying the results after all. Auger "should have been more careful" before publishing the 2007 paper, says Avi Loeb, an astrophysicist at Harvard University in Cambridge, Massachusetts.

The Auger physicists contend that it would have made no sense to wait. "We gave the statistical significance of what we observed, so scientists know how to ponder the results," says team member Esteban Roulet, a physicist at the Balseiro Institute in San Carlos de Bariloche, Argentina. "I think it is important that the community gets the information we can gather in this way."

## MASSIVE UPGRADE

Nonetheless, the mystery remains unsolved — an impasse that the Auger team wants to end with the hoped-for upgrade. The basic strategy is to get a better measure of each primary cosmic ray's mass and thus distinguish the relatively undeflected protons from the heavier particles, says Auger team member Alberto Etchegoyen, a physicist working at Argentina's National Atomic Energy Commission in Buenos Aires. "If nature is kind enough to us," he says, and if there are enough protons among the ultra-high-energy cosmic rays to get adequate statistics, "we'll be able to find the sources".

Currently, the mass is measured by Auger's fluorescence telescopes, which watch how each air shower expands and deposits its energy as it descends through the atmosphere. But the telescopes can operate only on clear, moonless nights, which cuts down on their observing time. So instead, the team wants to look within the showers to count muons: short-lived particles that behave like heavy electrons. Because the muons in air showers tend to be produced most copiously in collisions of heavier cosmic-ray particles, knowing their abundance should tell the Auger physicists whether the incoming primaries are protons or heavy nuclei.

The five upgrade proposals represent five different ways of identifying muons, but all are based on the fact that the muons tend to penetrate farther into the water tank than other particles. Each scheme requires a different combination of new electronics, new detectors and internal modifications for all 1,600 tanks — hence the $15-million cost of the upgrade. Supporters argue that the investment is worthwhile, not least because the array currently has little chance of ever getting statistics good enough to identify the sources, yet still costs $1.7 million a year to run.

> "We have managed to grow a whole new generation of experimentalists."

But the muon-detection schemes have yet to be proved in the field, and the selection committee could still decide that the upgrade is not worth it — and perhaps even that Auger should be shut down. "This is a serious question," says Kampert.

Cronin insists that it is much too soon to give up. Auger is exploratory, he says. "I don't know how much we'll learn from it. But you don't learn anything if you don't do something."

Besides, says Allekotte, scrapping Auger would be depriving Argentina of a project that has greatly boosted the country's scientific capacity — not least by providing an incentive for young people to pursue physics. Tiny Malargüe now has a university for first- and second-year undergraduate students where many Auger engineers and scientists teach part-time. "One girl who started in 2012 was at first interested in maths, but as she learned more and more about the observatory and cosmic rays, she decided to switch to physics," says Marcos Cerda, an Auger engineer and a physics lecturer at the university. "She's now in her third year, doing a physics major at the University of Mendoza."

In addition, says Etchegoyen, there are many Argentinian students among the roughly 360 who have already earned their PhDs doing research at Auger, or are working towards one there. And now, he says, "two out of Auger's five upgrade proposals — design, prototype construction, everything — would be made in Argentina. That would've been impossible at the beginning of Auger. We have managed to grow a whole new generation of experimentalists linked to international big physics."

Thanks to the observatory, "Argentina appeared on the map of global science", says the country's science minister Lino Barañao. He points to the Deep Space Antenna 3 radio dish that the European Space Agency installed about 30 kilometres south of Malargüe to support space missions such as Mars Express, Herschel and Planck. And he points to the Large Latin American Millimetre Array, a radio telescope being built in the north of Argentina in collaboration with Brazil. The presence of Auger influenced the decisions to base both these projects in Argentina.

So if the Auger upgrade does go ahead, Argentina hopes to gain even more expertise, and add more capacity, says Barañao. And even if it doesn't, at least it's left a legacy. "We're associated with producing soya beans, beef and wine, but many countries can do that," he says. "Now we're also associated with world-class astrophysics." ■

**Katia Moskvitch** *is a science writer in London and an International Development Research Centre fellow at* Nature.


1. Bird, D. J. *et al. Astrophys. J.* **424,** 491 (1994).
2. The Pierre Auger Collaboration *Phys. Rev. Lett.* **104,** 091101 (2010).
3. The Pierre Auger Collaboration *Science* **318,** 938–943 (2007).
4. The Pierre Auger Collaboration *Astropart. Phys.* **34,** 314–326 (2010).