Do Comets Hold the Secret to Life on Earth?

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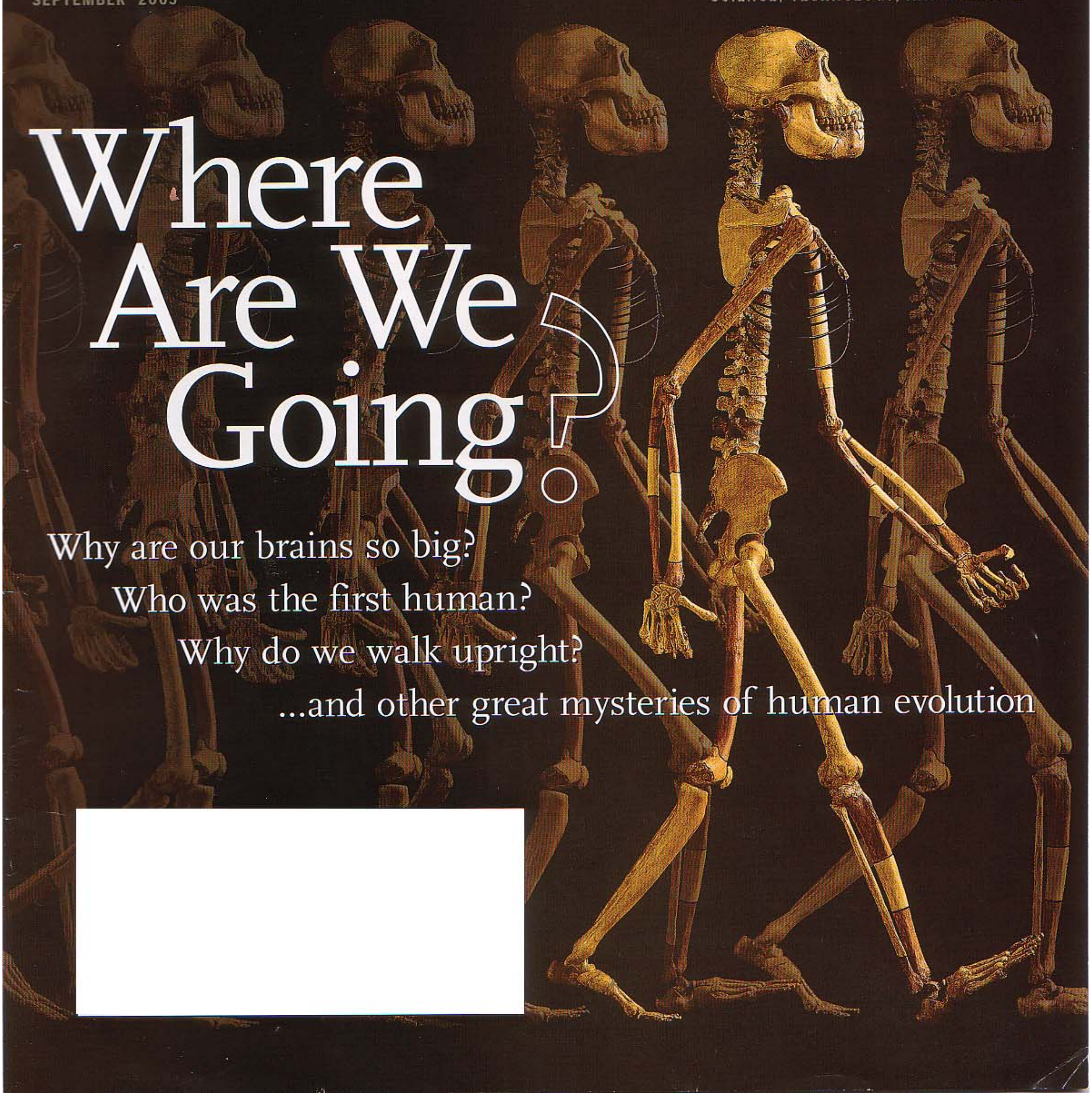
Discover

VOL. 24, NO. 9

SEPTEMBER 2003

SCIENCE, TECHNOLOGY, AND MEDICINE



Where Are We Going?

Why are our brains so big?

Who was the first human?

Why do we walk upright?

...and other great mysteries of human evolution

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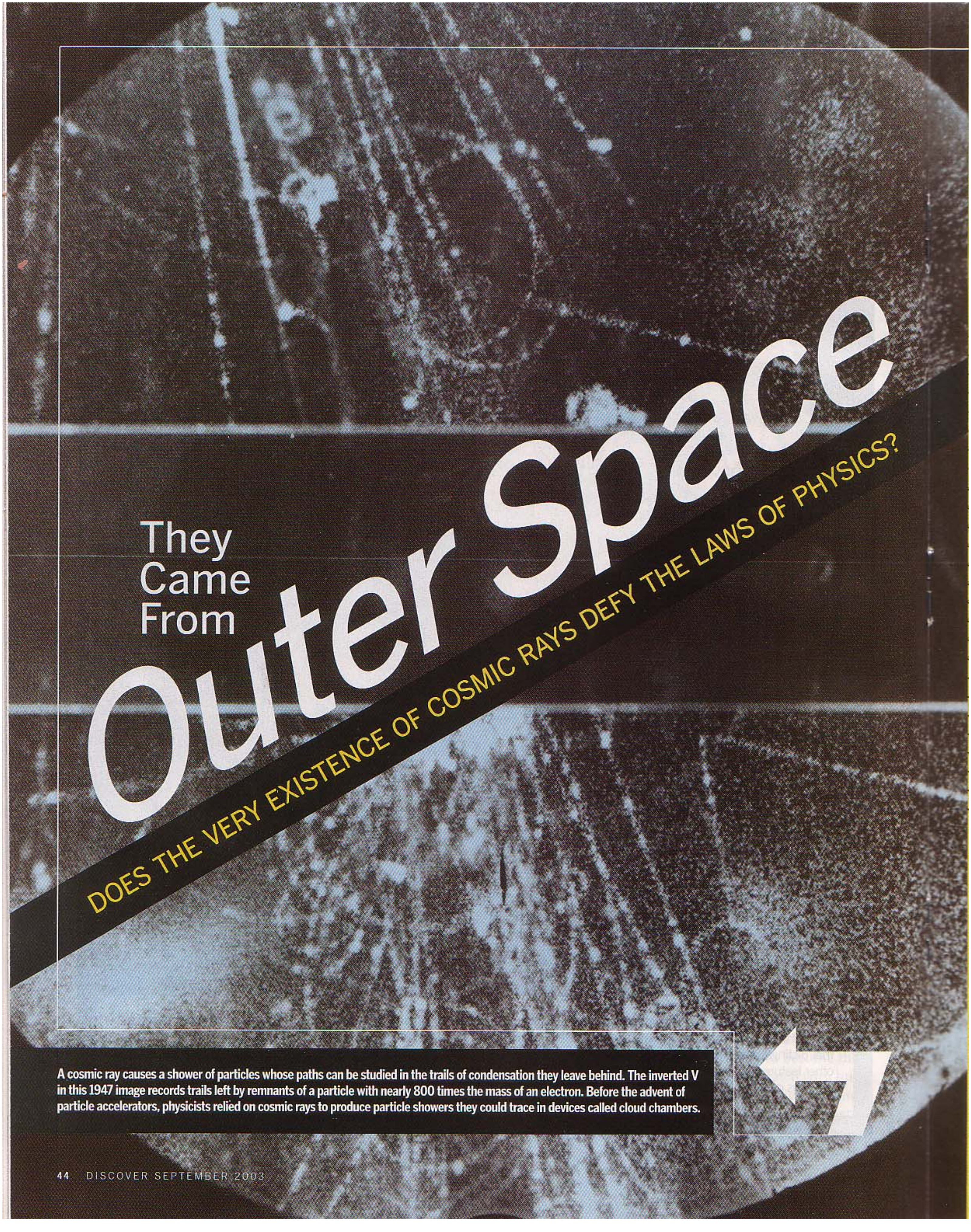
They Came From Outer Space

DOES THE VERY EXISTENCE OF COSMIC RAYS DEFY THE LAWS OF PHYSICS?



A cosmic ray causes a shower of particles whose paths can be studied in the trails of condensation they leave behind. The inverted V in this 1947 image records trails left by remnants of a particle with nearly 800 times the mass of an electron. Before the advent of particle accelerators, physicists relied on cosmic rays to produce particle showers they could trace in devices called cloud chambers.

BY KAREN WRIGHT

ASTROPHYSICISTS CAN seem a bit conflicted on the subject of cosmic rays. For one thing, they call them rays, as if they were pure energy, when they're actually bits of matter. And they ignore most cosmic rays, which constantly bombard Earth in relentless droves, focusing instead on the wildly infrequent ultrahigh-energy ones. Finally, theorists acknowledge those rays may be the most energetic particles known, then say they shouldn't exist at all. ¶ Physicists do agree on one thing about cosmic rays, however: A better understanding of them and where they come from could shake the foundations of our understanding of the universe. A beefed-up dossier on powerful cosmic rays might challenge the most cherished totem of physics, the speed of light. Yet it was not until about a decade ago that readings from two instruments at opposite ends of Earth demonstrated the existence of the most powerful ultrahigh-energy cosmic rays, which enter the atmosphere with the energy of a tennis ball moving at more than 100 miles an hour—a huge amount of force packed into a microscopic particle. High-energy physicist James Cronin, at the University of Chicago, says, "With all we know about astrophysical entities, we still can't figure out how they accelerate particles to these energies."

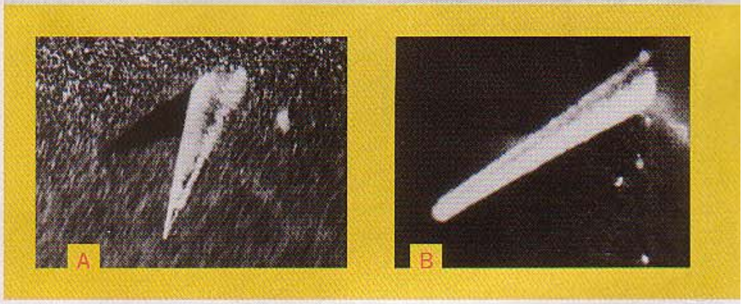
Physicists have long known that the rays consist of charged pieces of atoms, mostly protons from hydrogen atoms but also the nuclei of heavier elements. The vast majority don't deliver much of a wallop; most arrive with energies of about 1 billion electron volts (eV). Very few exceed 10^{16} eV. While that's still more moxie than a state-of-the-art particle accelerator can provide, cosmic rays don't pose a health hazard, because they collide with air molecules in the atmosphere. Each collision prompts a cascade of other impacts, a chain reaction that spreads a ray's energy among billions of particles.

The origins of common, low-energy cosmic rays aren't especially mysterious. Many are probably intragalactic drifters that got caught up—and accelerated—in the rapidly expanding shock waves of exploding stars called supernovas. The sun can also produce energized particles in solar flares or boost them on the solar wind, a plasma stream that pours continuously into space. But none of these heavenly accelerators has enough guts to generate a particle with 3×10^{20} eV—and a detector in the Utah desert recorded just such a particle in 1991.

"We didn't want to see it," says astrophysicist Pierre Sokolsky of the University of Utah, a member of the team that operates the Fly's Eye instrument and its successor, HiRes, at the Dugway Proving Grounds about 100 miles southwest of Salt Lake City. Sokolsky knew that standard physics couldn't explain such a powerful ray. There are sources in deep space that could provide enough acceleration: Bright, tumultuous galactic cores, called quasars, for example, would be likely suspects, as would the stellar explosions responsible for gamma-ray bursts. But those cataclysmic generators are billions of light-years away, and a separate line of analysis shows that ultrahigh-energy cosmic rays don't travel well. In particular, cosmic rays with energies above the 5×10^{19} eV "cutoff" are subject to disastrous collisions with photons from the background radiation that pervades space. The collisions so sap a cosmic ray's strength that within about 150 million light-years of movement, its energy is no longer ultrahigh. "Our assumption was that anything above the cutoff indicated a problem with the detector," Sokolsky says.

In 1993, after Sokolsky and his colleagues had exhausted other explanations for their data, they published the findings. Then a detector team in Japan reported two rays of the same order of magnitude, and both teams have independently logged subsequent ultrahigh-energy events. But because some of these sightings have been called into question, researchers studying ultrahigh-energy cosmic rays have at present less than a dozen undisputed incidents to examine.

"The problem is that these particles are so exceedingly rare," says astrophysicist Bob Streitmatter, leader of the high-energy cosmic radiation group at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The sky may be lousy with low-energy cosmic rays, but rays in the 10^{20} eV range come along at a rate of only slightly more than one per square mile per century.



So detectors must cover big swaths of air or vast stretches of ground to see anything at all. The signal they look for is an air shower: the chain reaction created by a powerful ray that causes charged particles to rain down on Earth. If it could be seen, the shower—lasting just 10 to 100 microseconds—would be quite a show. After the initial impact, secondary collisions with nitrogen atoms in the atmosphere release bursts of faint ultraviolet light at the leading edge of the cone-shaped cascade. Unlike those unleashed by lesser particles, ultrahigh-energy air showers reach all the way to the ground. "It's a very dim, glowing pancake of particles a couple of feet thick and 50 feet wide moving close to the speed of light," Sokolsky says.

The ultraviolet bursts are too dim for human eyes to register. But on clear, moonless nights, the mirrors in HiRes can pick them up. Japan's Akeno Giant Air Shower Array, in contrast, records the footprint of secondary particles that land on scintillation counters spread out over 60 square miles of ground. The differing methodologies probably explain at least some of the discrepancies that have plagued the research. So an international consortium of more than 200 physicists from 15 countries is building an instrument that combines both approaches: the Pierre Auger Cosmic Ray Observatory, named

PHOTOGRAPHS: PREVIOUS PAGES, GEORGE ROCHESTER; THIS PAGE, NASA (3).

for the French scientist who discovered particle showers in the 1930s. It will span 1,200 square miles of the Argentine pampas and should be both more sensitive and more reliable than any existing detector when it is completed in 2005.

An even more ambitious plan uses satellites in orbit to view broad reaches of Earth's atmosphere from above. Streitmatter is the lead scientist on NASA's proposed Orbiting Wide-angle Light-collectors, known as OWL. Another instrument, sponsored by the European Space Agency, may be mounted on the International Space Station by 2008.

Detailed measurements from the next generation of detectors will help astrophysicists evaluate competing theories about the origins of cosmic rays. One class of theories, known as the bottom-up brand, suggests physicists may have underestimated the accelerating drive of powerful astrophysical features that are relatively close to Earth. For example, colliding galaxy clusters and magnetars—superdense stars with very high magnetic fields—eject particles with vicious speed. Gas jets issuing from some galaxy-forming regions can strew debris across millions of light-years of space.

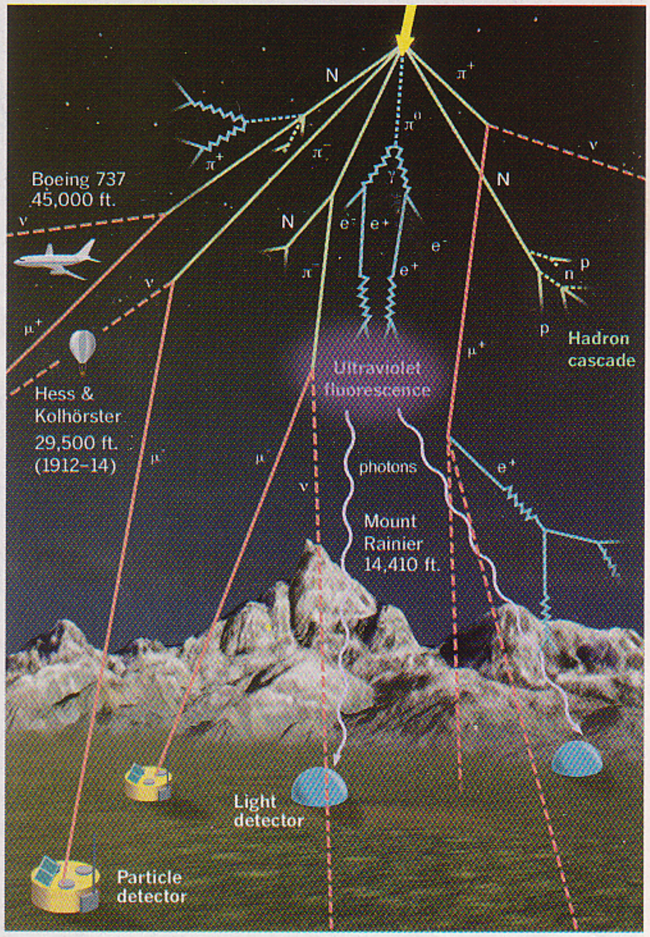
"These are the largest accelerators we've seen," says Angela Olinto, an astrophysicist at the University of Chicago. But active galactic nuclei and other celestial powerhouses create an energetic maelstrom that could just as soon suck in a particle as spit it out. "And we still don't know if the energy of the particles in the jets is as high as we need [to explain cosmic rays]."

COSMIC HARD HAT: The plastic helmet (top) worn by Jim Lovell during the *Apollo 8* lunar mission in 1968 bears microscopic pits left by bombarding cosmic rays. Figures A and B are silicone rubber replicas of the tracks cosmic rays left in helmets worn by astronauts on the *Apollo 12* mission. The tracks shown are about a fiftieth of an inch long. Studies of such impacts alerted researchers to the need for better shielding for astronauts during missions into deep space.

The second group of theories, known as top-down, depends on hypothetical wrinkles in the fabric of space-time that trap energy left over from the Big Bang. These defects, which are known as cosmic strings, are thought to have formed when sectors of the young cosmos cooled at different rates—just as cracks can develop when freezing water turns to ice. If the strings occasionally decay, they would release a menagerie of particles and waves with energies exceeding 10^{22} eV. The wrinkles would have to be created no later than 10^{-30} second after the Big Bang: "We'd need to get very close to age zero to reach the energies we're talking about," says Olinto. Cosmic-string theorists, whose models could explain the origins of some fundamental forces, have long awaited an empirical sign of the strings' existence. Ultrahigh-energy cosmic rays might fit the bill.

But in the string scenario, most of the decay would occur in the form of photons—waves of radiation, or energy—rather than protons and heavier atomic nuclei, the particles of matter that are supposed to make up cosmic rays. Does that rule out strings? When pressed, astrophysicists admit that high-energy photons and particles have air-shower signatures that are hard to distinguish. They now wonder if ultrahigh-energy cosmic rays are, in fact, matter. Could the rays actually be energy, as the name has always implied? "As long as you're talking about only a handful of events, you're not going to resolve this issue," says Sokolsky.

Some physicists argue that at high energies, even the speed of light may vary—posing a serious problem for Einstein's special theory of relativity, which states that the speed of light is constant, always and everywhere. With a speed-of-light loophole, ultrahigh-energy cosmic rays could travel greater distances than the experts suppose without getting bonked by background radiation. Evidence of their sojourns should turn up in data from the next generation of cosmic-ray detectors. If the source of those most powerful of particles turns out to be far enough away, Einstein himself could get a makeover. ☒



The collision of a cosmic ray with an air molecule sets off a shower of subatomic particles and emissions of ultraviolet light that can be detected. Balloon experiments in 1912 provided the first evidence of this radiation.

Yellow arrow at top represents incoming cosmic ray (heavy ion)

μ^+	positive muon	———	π^+	positive pion	———	e^+	positron ———
μ^-	negative muon	———	π^-	negative pion	———	e^-	electron ———
v	neutrino	- - - - - -	π^0	neutral pion	- - - - -	p	proton ———
p	photon	∿∿∿∿	N	nitrogen ion	———	n	neutron - - - - -

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