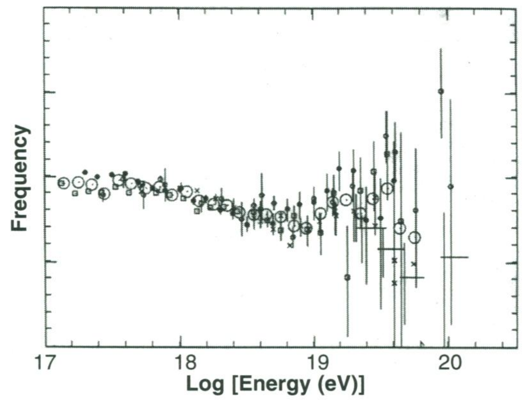
ASTROPHYSICS

Does a Cosmic Ray Gap Open The Door on New Physics?

In an old parlor game, one person draws pictures on a blackboard while the other participants frantically try to guess what they show. Cosmic-ray physicists now find themselves in a vastly larger version of this game. The picture they are squinting at is taking shape bit by bit as rare, ultrahigh-energy particles smash one by one into Earth's upper atmosphere, creating a brief glow and a shower of secondary particles. The result is a curve showing how often particles have been detected at particular energies, which range as high as 3×10^{20} electron volts (eV), millions of times higher than terrestrial particle accelerators can achieve. From the shape of this spectrum, physicists are trying to guess the nature of the fabulously energetic mechanisms that fling the particles through space.

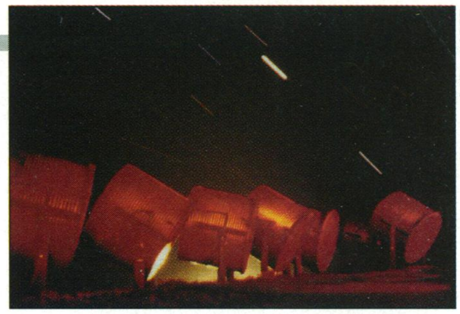
According to a new analysis of the data, part of the answer to this cosmic guessing game could turn out to be exotic even by astrophysical standards. On page 1977 of this issue, Günter Sigl, Sangjin Lee, and David Schramm of the University of Chicago and the Fermi National Accelerator Laboratory and Pijushpani Bhattacharjee of the Indian Institute of Astrophysics show that the spectrum could be hinting that the most energetic cosmic rays arise from "topological defects"—rifts in the structure of space that some cosmologists have proposed were left over when the universe cooled after the big bang. The group's statistical analysis, says Schramm, reveals that the data are "tantalizingly close" to showing that these energetic particles could not have been accelerated to those energies by the mechanisms proposed for lower energies.

The more exotic possibility, if it could be pinned down, "would be extremely important and interesting," says Todor Stanev of the University of Delaware, yielding insights not just into cosmic rays but also into the fabric of the cosmos itself. But the combination of high stakes and sparse data is bound to generate a host of proposals, and so far, says Stanev, "it's difficult to play favorites." Some researchers argue that the spectral shape doesn't rule out more traditional scenarios, in which known astronomical objects, such as radio galaxies, accelerate the particles. Still others advocate a third possibility: some kind of link between cosmic rays and the mysterious cosmological events called gamma-ray bursts (GRBs).



AKENO COLLABORATION

Rorschach for physicists. The cosmic-ray energy spectrum, measured at detectors around the world, seems to show a gap just below the highest energies.


GARY HIGBEE

Eye on the sky. The Fly's Eye detector in Utah records the atmospheric fluorescence from the highest energy cosmic rays.

What has spurred all this theorizing is an apparent gap in the cosmic ray spectrum, just below a handful of the most energetic events ever observed. Such a gap isn't expected for particles accelerated by energetic galaxies such as radio galaxies. Near the ends of the gargantuan plasma plumes that jet from these galaxies, researchers believe that shock waves traveling near the speed of light sweep up magnetic fields and any charged particles clinging to them. The trapped particles can gain large amounts of energy by bouncing repeatedly back and forth between the shock waves' narrowing walls.

Because the particles are boosted in a "bottom-up" fashion from low energies to high and have a chance of escaping each time they bounce, such mechanisms should result in a frequency spectrum that drops off smoothly at higher energies—not a gap. Sigl and co-workers' statistical analysis showed that there was just a 10% chance that radio galaxies or some other bottom-up mechanism in the distant universe would yield something like the actual, observed spectrum by chance.

In the scenario the Fermilab group suggests, the particles above the gap are the offspring of events in the early universe, when the "gauge fields" describing the properties of space might have frozen into different solutions in different regions. The intersections of these regions could have spawned hypothetical particles known as magnetic monopoles—in essence, isolated magnetic north or south poles. Over 10 years ago, Fermilab's Christopher Hill showed that pairs of monopoles could be stable for billions of years, vanishing only when they spiral together and annihilate into particles and photons with tremendous energies. More recently, in work to appear in *Astroparticle Physics*, Thomas Weiler and Thomas Kephart of Vanderbilt University suggest that monopoles themselves might be slamming into the upper atmosphere, having been accelerated by the

Southern Strategy for Ray Detector

Physicists' eagerness to solve the mystery of high-energy cosmic rays (see main text) seems to be matched by Argentina's eagerness to snare part of the project that could do so. During a meeting in Paris on 20 to 22 November, physicists from 19 countries not only formalized the Pierre Auger project, which aims to construct large detector arrays in the southern and northern hemispheres (*Science*, 1 September, p. 1221), but also chose Argentina as a site for the southern detector. The South American choice came, not coincidentally, after participants learned that Argentina "promised explicitly" to provide $15 million for the project and its neighbor, Brazil, informally offered another $10 million, says James Cronin of the University of Chicago, the project's spokesperson.

Cronin notes that these contributions are contingent on the collaboration's ability to raise the rest of the money from other sources. But as the overall cost is expected to run about $100 million, the Latin American bid for the site was "pretty overwhelming," says Fermilab's Paul Mantsch. "You can't disregard that level of support," says Mantsch about the choice of Argentina over Australia and South Africa.

Each array would consist of thousands of detectors spread over 3000 to 5000 square kilometers. The combined observing power would help researchers capture hundreds of times more ultrahigh-energy cosmic rays than have been detected so far. Construction could come another step closer in June, when the collaboration will meet to seek additional funding and choose a northern site.

–J.G.

Milky Way's weak magnetic field over huge distances to just the energies required.

For the moment, such radical suggestions won't find a ready audience among astrophysicists, says Mario Vietri of the Osservatorio Astronomico di Roma in Italy. "Before crying wolf, one ought to try to rule out all possible ... explanations based on well-tested physics," he says. The spectral gap could easily result from random and systematic errors in the measurements, say some physicists. "We have thoroughly debated the 'gap,' which some wish to see in the data," says Peter Biermann of the Max Planck Institute for Radioastronomy in Bonn, Germany, "and we just do not see any basis for the claim that the gap is real." Adds Biermann, "Radio galaxies are—in our view—the best conventional answer at this time." He notes that they could even explain a dip—although not a gap—if the total flux is the sum of distant radio-galaxy sources, whose spectra would be clipped by interactions between the particles and the microwave background radiation that permeates space, and nearer sources, which wouldn't feel the effect.

But Eli Waxman of the Institute for Advanced Study in Princeton, New Jersey, notes that there are other alternatives. Earlier this year, Waxman and then, independently, Vietri, noted an apparent link between the upper end of the cosmic-ray spectrum and GRBs, mysterious flashes of gamma rays that appear about once a day from random directions in the sky. Waxman and Vietri pointed out that the total energy output from GRBs, assuming they lie in the far reaches of the universe, is nearly equal to the total energy of cosmic rays above another prominent spectral feature, called the "ankle," at 3×10^{18} eV. The match-up fits some models of the GRB sources, which suggest that they should put out roughly equal amounts of energy in particles and photons.

And in soon-to-be-published work, Waxman and his colleague Jordi Miralda-Escudé have shown that if GRBs do somehow generate cosmic rays, their intermittent behavior could explain the gap. Because lower energy particles would take longer to arrive than ones at the highest energies, the gap might be a temporary feature, between the tail end of particles from earlier bursts and the first arrivals from recent ones. To suggestions that this replaces one mystery with another, Waxman replies, "I am reducing two mysteries to one—not replacing one with another."

Hopes for reducing the mysteries to zero rest, of course, with more data. For that, astrophysicists are counting on the proposed Pierre Auger project (see box). Its twin cosmic-ray detectors, covering thousands of square kilometers in the northern and southern hemispheres, should draw out the spectrum with total clarity. And that might finally end the guessing game.

–James Glanz

CHEMISTRY

Dendrimers Display Liquid Crystal Talents

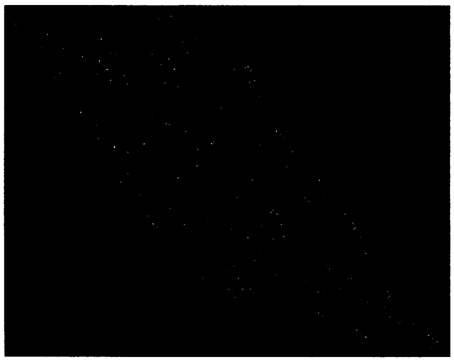
Dendrimers, which are densely branched polymers, have often been compared to snowflakes, and now chemists report they've been able to get these snowflakes to melt. Researchers have transformed these ball-like, intricately branched structures into rodlike liquid crystals (LCs)—the hybrid molecules that flicker between solid and liquid states to form watch and computer displays.

In the 22 November issue of the *Journal of the American Chemical Society*, Virgil Percec of Case Western Reserve University in Ohio and Goran Ungar at Sheffield University in England report they've been able to fabricate the first nonspherical dendrimers. The orientation of these molecules can be changed by an electrical field, in the same way as standard LCs are reoriented to display changing image patterns. Although dendrimer displays have not yet been made, Percec says the polymer-based technology could have several advantages over standard LCs beyond a lower cost. Typical LCs can only be affixed to small pieces of flat glass, but polymers can attach to a variety of surfaces in various shapes and sizes.

This novel dendrimer architecture is "beautiful" work, says dendrimer chemist E. W. 'Bert' Meijer at the University of Eindhoven in the Netherlands, and he agrees that it has technological promise. Others, however, caution that the dendrimers are still not up to the standards of conventional LCs.

Those LCs, which are rod or disk-shaped molecules, line up with a common orientation, like logs in a raft, even though they are not fixed into a crystal lattice. When an electrical field is applied, their orientation changes, altering their ability to transmit light through a display screen; that's how LCs display numbers. But LC materials can be expensive, and it is difficult to affix them in the proper starting orientation.

So chemists have long sought to coax LC behavior out of polymers, which are made of inexpensive building blocks and easily form flexible films that are easier to apply to a display screen. But standard polymers are hard to flip, because they are made of long chainlike molecules that get tangled up with one another. It takes larger electrical fields to move them, and even then they are slow to respond—not a good display feature.


G. UNGAR

The lineup. Monodendrons—wedge-shaped dendrimer components—align in a tilted liquid crystal phase in this model.

Dendrimers may be less prone to tangling because of their densely packed spherical shape—but flipping a sphere doesn't change its orientation or its optical properties. "Intuitively," Percec says, "one would not have expected that an LC dendrimer could be made."

Percec and Ungar decided to discard intuition in favor of synthetic chemistry. Typically a dendrimer is made from several generations of branched building blocks that form wedge-shaped molecules, known as monodendrons, which are then joined together to form the sphere. To build some asymmetry into this process, the chemists attached a crown ether—a small ring-shaped molecule—to each wedge point. These acted as binding sites, locking the monodendrons together in a tapered cylinder. (In an alternate scheme, the chemists began with a rod-shaped LC monomer and built monodendrons around it to produce liquid crystal dendrimers.)

In an electric field, these nonspherical dendrimers flipped their orientation but maintained their relative positions, just like ordinary LCs. And as Percec had hoped, the power required to induce this flip was lower than that needed to flip linear polymers. A 1 tesla field, the researchers found, easily flips a dendrimer with four generations of branches. It did nothing to a linear polymer of equivalent mass. Percec suspects the compact geometry of the dendrimers—compared to polymer chains—is responsible and plans to verify this structure with neutron scattering experiments.

The flips might make it possible to produce a variety of screens with fast refresh rates. But dendrimer LCs aren't ready to go on display quite yet, says LC specialist Robert Lewis of the University of Hull, England. They are still harder to flip than standard LCs, for one thing. Percec, however, thinks that it might be possible to reduce their molecular weight still further, making it easier to flip them. And then polymer-based LCs will no longer be such a tangled problem.

–David Bradley

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