would ultimately serve to test Weiler's hypothesis.

Another way of allowing very distant sources without a GZK cutoff below 10^{20} eV is suggested by Glennys Farrar (now at New York University) and colleagues.[3] They point to a relatively light supersymmetric hadron, designated S^0, whose existence was predicted in the mid-1980s in attempts to expand the standard model. If the S^0 really exists, this neutral bound state of three quarks and a light gluino (the putative supersymmetric partner of the ordinary gluon that holds quarks together) would have all the right properties for explaining the AGASA spectrum, *and* it has not yet been excluded by accelerator searches. Its predicted mass (two or three times that of the proton), neutrality and rather large energy gap before its first pion-production resonance all conspire to let it traverse cosmological distances through the CMB without falling below 10^{20} eV. Simple kinematics tells us that any really heavy hadron could do that, but if it were much heavier than the S^0, it would not lose enough energy in the atmosphere to simulate a high-energy proton shower.

Looking backwards

In both the Weiler and Farrar conjectures, the incident direction of an ultrahigh-energy cosmic-ray shower should point back to its distant astrophysical source. That's because the intergalactic traveler is electrically neutral and therefore impervious to the magnetic fields that bend the trajectories of protons and nuclei. Farrar and Peter Biermann (Max Planck Institute for Radio Astronomy in Bonn) have looked for likely sources in the directions of the five highest-energy cosmic-ray showers for which celestial coordinates are available.

In an upcoming issue of *Physical Review Letters*, they report that every one of these five, within its directional error box on the sky, points back to a compact radio-loud quasar.[4] "The odds against this happening by accident are 200:1," Farrar told us. "We impatiently await AGASA's announcement of the direction of its most recent 10^{20} eV event, so we can go and look." (At these ultrahigh energies, even proton trajectories are so magnetically rigid that they would point back to within a few degrees of their sources.)

Not all the schemes for evading the GZK cutoff involve distant astrophysical sources one could find with a telescope. A number of theoretical conjectures posit the existence of long-lived supermassive particles—with perhaps 10^{12} times the proton mass—either left over from the Big Bang or appearing as decay products of primordial topological defects of the presumed cosmic scalar field. When these supermassive particles finally decay, 10^{20} eV protons and photons would be among their products. The GZK cutoff is circumvented by assuming that the resulting cosmic-ray spectrum we see is dominated by the decay of superheavies accumulated in the local cluster of galaxies.[5] As in Weiler's scheme, the majority of ultrahigh-energy primaries would be photons (from π^0 decay) rather than protons.

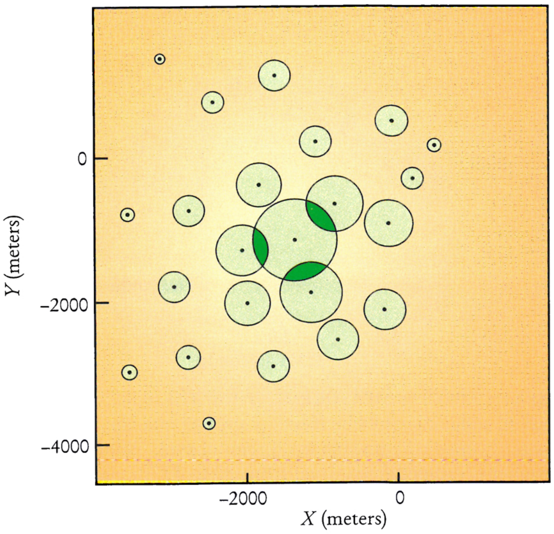

FIGURE 3. PATTERN OF SIGNALS recorded in 23 of AGASA's individual scintillation detectors for a record 2×10^{20} eV event observed in 1993 (second only to a 3×10^{20} eV event recorded by the Fly's Eye). Each AGASA detector is 1 km from its nearest neighbor. The circle widths are logarithmic measures of the number of charged shower particles recorded by each detector.

Looking forward

The most ambitious of the observational proposals still on the drawing boards is the Pierre Auger Project, headed by James Cronin (University of Chicago). Cronin and collaborators propose to build a pair of 3000 km^2 giant air shower arrays, one in Utah, the other in Argentina. Each ground array is to be augmented by atmospheric-fluorescence telescopes that image a high-energy cosmic ray shower passing overhead by the nitrogen fluorescence it generates. In July, DOE and NSF finally approved \$7.5 million for the first four years of construction funding, provided that the construction begins with the Southern Hemisphere site and that Argentina contributes its share of the cost.

Currently nearing completion, also in Utah, is the High Resolution Fly's Eye Detector (HiRes), headed by Pierre Sokolsky (University of Utah). HiRes is the binocular offspring of the original Fly's Eye, the prototypical mosaic fluorescence telescope.

"When we start taking binocular data next fall," Sokolsky told us, "we'll already have two years of monocular HiRes data in hand. Assuming the published AGASA spectrum is right, our group should have about 16 events beyond 10^{20} eV by then. So, if the cosmic-ray spectrum really is thumbing its nose at the GZK cutoff, we should all know it with great confidence a year from now, having measured these elusive energies by two quite different techniques."

BERTRAM SCHWARZSCHILD

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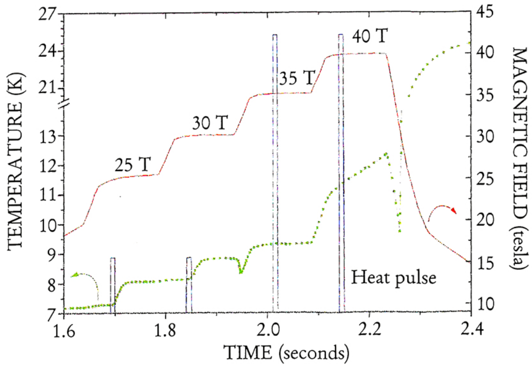
Long-Pulse 60-Tesla Magnet Starts Routine Operation at Los Alamos

For experiments in very high magnetic fields, there are DC electromagnets that have operated continuously at fields as high as about 35 tesla, and the National High Magnetic Field Laboratory (NHMFL) expects to generate fields close to 45 T early next year. Some high-field DC magnets are purely resistive, others are hybrids

With the long-pulse 60 tesla magnet now running at Los Alamos, you can study electrical and magnetic properties of many materials.



HEAT CAPACITY MEASUREMENT for $YbInCu_4$. At 25 and 30 tesla, a heat pulse (blue) is applied and the thermometer comes to equilibrium (green curve). When the magnet is ramped (red curve) from 30 to 35 T, a downward spike in the temperature occurs as the first-order phase transition is crossed. (Figure courtesy of Roman Movshovich, Los Alamos.)

that also contain a superconducting magnet. For higher fields, pulsed technology has been employed. The highest magnetic fields for experiments are produced in self-destructing magnets, in which the pulse lasts a few microseconds before the magnet destroys itself.

Long-pulse magnets

Most of the pulsed magnets in operation are basically an *LC* circuit. Once such a capacitor-driven magnet is built, the pulse shape is pretty well determined—it's a sine wave distorted only by the finite resistance of the magnet.

Another possibility, pioneered at the University of Amsterdam, is to control the magnet with a power supply so that one can change the pulse shape and define the field as a function of time. Amsterdam built such a magnet that operated at 40 T and had a pulse duration of as much as 500 ms. The magnet was operated as an experimental facility for more than two decades.

Recently, at the end of August, a 60 T long-pulse magnet that follows the Amsterdam approach was dedicated at Los Alamos National Laboratory. Its pulse can be shaped and its duration at peak field is as much as 100 ms. The $6 million facility reached 60 T last fall and the first experiments, by Los Alamos users, began in the spring while NHMFL was learning how to operate the magnet. Next month the magnet will be open to outside users.

When the National Science Foundation decided to establish NHMFL in 1990, it was agreed the lab would have three campuses—at Florida State University in Tallahassee, at the University of Florida in Gainesville and at Los Alamos. From the beginning it was clear that Los Alamos had a unique resource, a 1.4 GW synchronous motor generator purchased from a canceled nuclear power plant and intended for the Los Alamos fusion device called ZTH. That motor generator enabled the 60-T long-pulse magnet to be built.

As Don Parkin of the NHMFL Los Alamos Center explains, if you wanted to build a 60 T electromagnet, you would need to either find wire with the conductivity of copper and the strength of steel or distribute the force across a set of nested reinforced coils. The high-field long-pulse magnet has nine nested coils that are mechanically independent and free standing, and enclosed in a steel reinforcing shell. The generator provides AC power to five AC–DC converters rated at 64 MW each. The converters energize three independent coil circuits to produce a maximum field of 60 T containing 90 MJ. The coil windings are made of a copper matrix with tiny particles of alumina to impede dislocation motion. This material gives high strength and enough ductility to be wound, and its conductivity is 80% as high as that of pure copper. Prior to a pulse, liquid nitrogen is used to cool the 4-ton magnet. The liquid nitrogen is then drained off to avoid the risk of an explosion due to its rapid vaporization as the magnet heats up. After the pulse, it takes an hour to cool the magnet back down so that the next pulse can be produced.

The best capacitor-driven magnets can reach above 70 T but only operate below 90% of the peak field during most of their 10–100 ms pulse, says Parkin. In the new 60 T long-pulse magnet, says Greg Boebinger, director of the NHMFL Los Alamos Center, the pulse can last 1 s going up and 1 s going down, and you can shape the pulse to produce a flat top at the top of the pulse, or to produce a stair-step pulse, for example.

The magnet is 1 m high and has a 32 mm bore. Because a cryostat must also occupy the bore, the available space for temperature-controlled experiments is 25 mm diameter, making tens to hundreds of cubic centimeters available for high magnetic field experiments, says Boebinger.

Experiments at Los Alamos

The low ramp rate and lengthy constant-field plateaus have inspired the development of brand-new tools. Roman Movshovich and Marcelo Jaime (Los Alamos) have developed a probe to measure heat capacity. A known amount of heat is delivered to the sample using a chip resistor as a heater. The heat capacity is determined as the ratio of the heat delivered to the sample to the change in the sample's temperature. The low ramp rate (340 T/s) reduces the unavoidable eddy current heating in metallic samples (in comparison with short-pulse, capacitor-driven magnets) and the flat-field plateau allows the heat capacity cell and sample to reach thermal equilibrium before and after the heat pulse.

The figure on this page shows the results of an experiment on a single crystal of metallic $YbInCu_4$, which had previously been found to have a first-order valence transition in a temperature and field range convenient for testing Movshovich and Jaime's specific heat equipment. By relying on the programmable nature of the 60 T magnet, they could study the sample at each of the four plateaus at 25, 30, 35 and 40 T, each lasting 130 ms, during a single magnetic field pulse. At 25 T, a known heat pulse (blue) is delivered, the thermometer comes to equilibrium (green curve); the same thing occurs at 30 T. When the magnet is ramped from 30 to 35 T, a downward spike occurs as the first-order phase transition is crossed because of the magnetocaloric effect. When the magnetic field is raised further, the internal relaxation time in the high-field phase is too long for the thermometer to reach equilibrium.

Another early experiment at the Los Alamos long-pulse magnet was done by Hong-wen Jiang (UCLA) and his collaborators. They studied photoluminescence in a two-dimensional electron system. By shining a laser 2000 times on the sample during a single magnet pulse, the experimenters obtained a video with 2000 spectra.

Bigger and better fields ahead

Los Alamos has been funded by the Department of Energy for a joint DOE–NSF project to design and build a 100 T nondestructive magnet. The new magnet will have seven nested coils that produce 50 T in a 220 mm bore, and will resemble the newly commissioned 60 T long-pulse magnet with the inner five coils removed. Within the 220 mm bore will be a capacitor-driven magnet, which will be fired to produce the additional 50 T, yielding 100 T in the millisecond range. At present the only magnets to produce a megagauss have produced 100 T in microseconds before self destructing. So Los Alamos expects to be the first lab to produce a nondestructive megagauss field. It is funded to build the magnet in fiscal year 2000 and to have the magnet installed and commissioned in FY 2001.

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