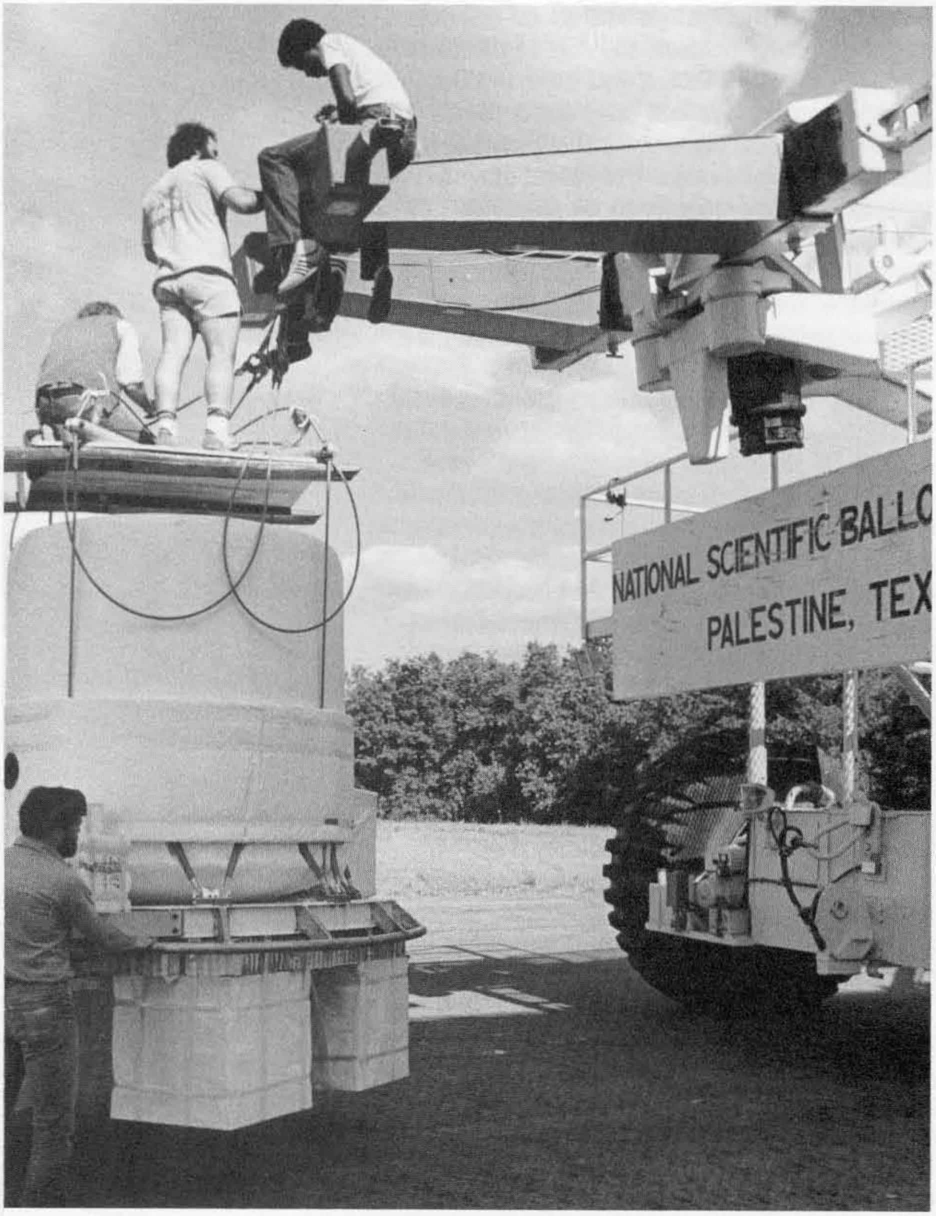
Cosmic Heist



A 60-ton crane called Tiny Tim prepares to hoist HEIST for the first leg of its journey to intercept cosmic rays in the troposphere.

THE LARGE, METAL BUILDING might be expected to house tractors, considering that it sits up a forest road amidst the fields of rural east Texas. However, its three-story steel doors open to reveal, not farm machinery, but several strange white agglomerations of boxes and cylinders, each suspended from the ceiling by heavy cables.

Scattered among these large, awkward-looking shapes is an assortment of computers, terminals, tools, spare parts, and workbenches. The afternoon of May 12, 1984, sees a half-dozen scientists, engineers, and technicians at work checking out one of these packages, an ungainly six-foot-high cylinder festooned with assorted boxes and wires. The only bits of color on it are four small, orange Caltech pennants on its steel cable harness.

If all goes well on May 12, these pennants will soon wave in the thin, cold air more than 20 miles above the earth; the 2,600- pound instrument called HEIST will be borne aloft by an immense 17-million-cubic-foot balloon from the National Scientific Balloon Facility near Palestine, Texas. HEIST's mission: to intercept high-energy particles that have ricocheted throughout the galaxy for millions of years.

These particles may be the ashes of long-dead stars, expelled in the convulsive explosions called supernovae that marked their end. Or else, the particles may be cold space dust caught up in the shock wave from a supernova as it sweeps through space. This high-energy stardust — more commonly known as cosmic rays — consists of the atomic nuclei of elements from hydrogen through uranium, accelerated to velocities ranging from a few percent to more than 99 percent of the speed of light.

HEIST, for High Energy Isotope Spec-

by Dennis Meredith

trometer Telescope, represents a brand new approach to detecting and sorting out the fine differences among heavier, high-energy particles — ranging between neon and iron, at energies up to a few billion electron volts. So far, May 12 looks like an excellent day for the first test.

The Balloon Facility meteorologists have declared that the low-level evening winds may be just right for the balloon launch; and that the upper-level winds are unlikely to carry the balloon too far in its planned two-day mission — either south toward the Gulf of Mexico or to the east or west. Indeed, certain periods of the spring and fall are called turnaround periods, when the high-altitude winds are more likely to dither back and forth with relatively little net movement to blow a balloon too far from its launch point.

A forklift eases into the hangar, and its operator gingerly maneuvers the machine's prongs beneath HEIST's harness. The prongs rise, lifting the package so that it can be detached from the suspending cables. As the forklift retreats slowly out the door with its cargo, the Caltech scientists and engineers carefully shepherd it along. Perched atop the ponderous instrument are the project leader, Senior Scientist Stephen Schindler, and Marty Gould of Caltech's Central Engineering Services, which was responsible for most of the mechanical work of building HEIST. Also manning the launch are William Althouse, technical manager of Caltech's Space Radiation Laboratory (SRL); Senior Research Associate Richard Mewaldt; HEIST technician Wallace Campbell; and Caltech graduate students Koon Lau, Eric Christian, and Eric Grove.

The forklift stops and waits. A sultry breeze offers a worrisome rebuttal to the meteorologists' prediction of calm. After a few minutes the roar of a large engine is heard through the trees, and into view comes what looks like a giant child's Erector set toy. Rolling smoothly toward the hangar is an odd- looking, 60-ton crane called Tiny Tim, from which HEIST will be launched. Tiny Tim rolls up to the forklift, and lowers a pair of red steel jaws into place above the instrument. The jaws are clamped shut on a crossbar at the top of HEIST's harness, and, revving its engine, Tiny Tim lifts HEIST easily off the forklift.

Another small forklift approaches, carrying the only means HEIST will have of controlling its flight — two 500-pound boxes of fine steel shot to be used as ballast. Dribbled out the bottom of the boxes via radio-controlled valves, the shot will lighten the payload to maintain altitude during crucial nighttime flight, when cooler air reduces the balloon's buoyancy.

The ballast attached beneath it, HEIST begins its journey toward the launching pad. The Caltech scientists grin as they walk beside Tiny Tim, steadying its load. After all, this is the culmination of some five years of painstaking work. The procession, consisting of the gangling Tiny Tim holding HEIST, the excited scientists, and various cars and trucks reaches the launch pad, a 2,000-foot-diameter paved circle carved from the forest.

The scientists begin to check out HEIST and its telemetry system. A hundred feet above them floats a small test balloon tethered near the launch pad. Its string slants downward at a 45- degree angle to the ground, telling of a steady breeze aloft. The balloon technicians attach the parachute, which will lower HEIST safely to earth, to the top of the payload harness. They also carefully lay out a ground cloth from Tiny Tim to the edge of the launch pad and sweep it; even a stray twig could ruin the whole launch, should it pierce the balloon.

Checkout is nearly complete, and the time has come to make the irrevocable decision to deploy the balloon. Once pulled from its large crate, the balloon cannot be repacked without increasing the danger that its delicate skin may be inadvertently pierced. A car makes its way across the pad with two balloon facility staff members. They bring bad news. Their instruments say winds near the ground are too high; the launch is scratched for that day.

The news is particularly vexing because

the weather is becoming increasingly unstable, and if HEIST does not fly during the next few days, it may miss the optimum turnaround season and perhaps be postponed until the fall. The workmen fold the ground cloth away, and trundle HEIST back to its hangar, leaving it hanging overnight from Tiny Tim's jaws in hopes of another chance; Schindler and his colleagues can only hope tomorrow's weather will be calmer.

They take the announcement in their stride, however; such problems are typical of any radical new instrument, and they have met many since the project was begun in 1979. It was then that the scientists, working at SRL with Professor of Physics Edward Stone, began casting about for a new approach to capturing cosmic rays. They were particularly interested in sorting out the fine differences in isotopes of heavy, high-energy cosmic rays. Isotopes are the nuclei of those elements that possess identical chemical properties, but which differ in their masses because of differing numbers of neutrons in their nuclei. The group, working with Stone and Rochus Vogt, now Caltech provost, had already developed the first low-energy isotope spectrometer, which was launched on NASA's ISEE-3 spacecraft in 1978.

The isotopes of heavier particles, in particular, possess unique information about the history of cosmic rays. For instance, the abundance of certain radioactive isotopes of cobalt, nickel, and iron can give scientists a measure of the time between their birth in the furnaces of stars and their acceleration. This is because these isotopes decay only as atoms with orbital electrons, and not as stripped nuclei traveling at high speeds. Still other radioactive isotopes of aluminum, chlorine, calcium, manganese, or iron can function as cosmic ray "clocks" to measure how long the cosmic rays had been rattling about the galaxy after being blasted to high energies by exploding stars.

To distinguish among these isotopes, the instrument had to resolve extraordinarily fine differences in mass, as little as a few tenths of a percent. The scientists also wanted a detector that had enough mass to slow the high-energy particles that range up to about 2.5 billion electron volts. At these high energies, they could be sure of a clearer picture of the cosmic rays streaming through the galaxy; high-energy particles are less likely to be affected on their voyage into the solar system by the solar wind — the low-energy stream of particles constantly billowing out from the sun.

And finally, the new instrument had to operate reliably while being lofted into the harsh reaches of the upper atmosphere beneath a balloon, and to survive being parachuted back to earth. The instrument was to be balloon-borne, because even in the rocket age balloons remain the ideal way to test large experiments in the upper atmosphere — at a small fraction of the cost of a rocket launch. The balloons can float for days in the upper atmosphere, acting as stable platforms for instrument packages that can be easily recovered near the launch point. So the Texas Balloon Facility is in considerable demand, sending some 60 flights aloft each year, carrying a wide variety of instruments for cosmic ray studies; gamma and X-ray studies; optical, ultraviolet, and infrared astronomy; atmospheric research; studies of the earth's magnetosphere; and attempts to capture micrometeorites.

It was Senior Research Associate Andrew Buffington who made the calculations that showed the way for Caltech's balloon experiment. His studies showed that a stack of sodium iodide disks — long used as the basis of gamma ray cameras in the medical imaging technique of positron emission tomography — could provide enough mass to slow the high-energy particles. At the same time, the number of fragmenting particles would be kept to a reasonable level in such an instrument. Thus, large sodium iodide crystals could serve as the basis for a scintillation counter, which, combined with other detectors, could resolve the isotopes.

Scintillation counters consist of materials whose molecules are excited by the impact of high-energy particles. After the particle has passed, these excitations relax, producing faint flashes of light that can be detected by photomultiplier tubes surrounding the material. The scientists and engineers designed HEIST as a stack of 12 circular plates of sodium iodide, each 0.5 meters in diameter and two centimeters thick. Surrounding each of these highly polished disks would be six photomultiplier tubes, each sending its signals to an onboard computer.

But HEIST needed to do much more than simply sense when a cosmic ray particle plowed through it. In order to resolve the minute mass differences among isotopes, it had to tell the researchers precisely at what angle and position the particle traveled, so that they could correct for the variations in thickness of material seen by the particle.

HEIST's design allowed for this fine measurement. By comparing the respective strength of signals from different photomultipliers aimed at a given disk, the scientists could tell just where a cosmic ray passed through the disk. By comparing signals from several disks, the scientists could trace the particle's path precisely.

New high-precision electronic circuits had to be developed by Caltech engineers William Althouse and John South to measure accurately the 108 different signals generated in the detectors. To function properly, the circuits had to be small in size, draw little power to minimize consumption of onboard battery power, and be inexpensive enough to produce in large quantities. The final result fitted on a thin printed circuit board less than two inches square and used less than one watt of power.

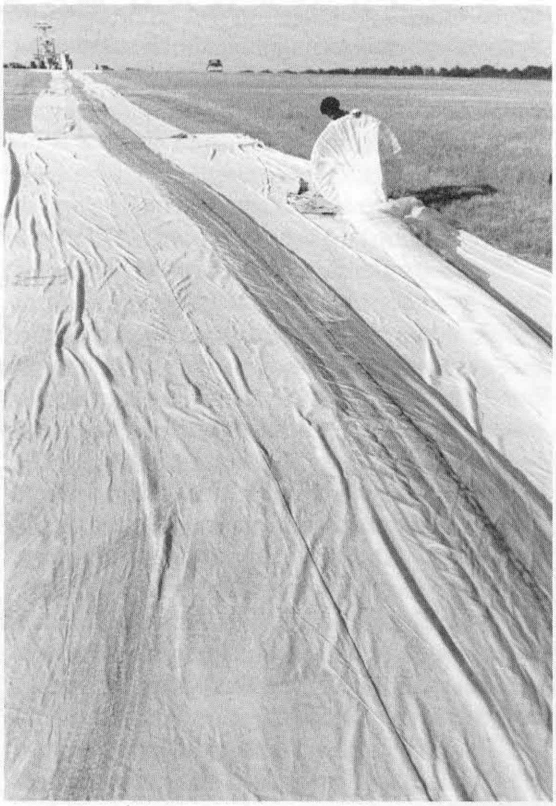
To calculate the particles' energies, the scientists had to know how fast they streamed through the instrument, a capability supplied by Danish space scientist Ib Rasmussen. Working with the Caltech scientists, he developed a pair of Cerenkov radiation detectors to be installed above and below the sodium iodide crystals, like the bread of a sandwich.

Cerenkov radiation is the tiny flash of light produced when a charged particle plunges through a material at greater than the speed of light *in that material.* The radiation is a sort of electromagnetic shock wave generated along the particle's wake. (Of course, nothing can exceed the speed of light in a vacuum, but light travels more slowly through matter. For example, particles can travel up to 1½ times faster through glass than can light.)

HEIST's Cerenkov detectors consisted of three kinds of material — above the sodium iodide was a slab of light, foamed glass called an "aerogel" and below, a layer of Teflon and one of plastic. A particle from space would pass at higher speed through the aerogel, then would be slowed by the sodium iodide, and finally would plow through the Teflon and plastic. By comparing the intensity of flashes produced in the two Cerenkov detectors, the scientists could figure out the extent of the particle's slowing, and by combining this with the energy loss measurement in the sodium iodide, could determine the particle's mass and the energy it began with.

To insure that no data would be lost, HEIST would record all its data onboard, as well as transmit it via radio to the ground. The two onboard recorders would be nothing more elaborate than commercial videocassette recorders, each of which has about 10 times the storage capacity of commonly used magnetic tapes. And overseeing the flight would be a microprocessor similar to those found in

Technicians lay out a clean ground cloth from Tiny Tim to the edge of the launch pad for the empty balloon to lie on. Even a twig could pierce the balloon's delicate skin.



The unwieldy, giant balloon is hauled out of its crate and laid along the ground cloth (left); then the filling begins and the balloon swells into shape.

home computers. The microprocessor and its associated circuitry was developed specifically for use on HEIST by Steen Laursen of the Danish Space Research Institute.

To Harshaw Chemical Co. of Solon, Ohio, went the job of fashioning the sodium iodide plates. It was a challenge for the company; the crystals had to be polished to optical quality, much higher than had ever been attempted. Rasmussen made the aerogel Cerenkov detector. The major task of building the mechanical portion of HEIST fell to Caltech's Central Engineering Services. CES engineers were already well known for their ability to build instruments to the exacting demands of science, and within its no-frills budgets. HEIST would prove to be one more feather in their cap.

HEIST's birth was accompanied by its share of challenges and adventures. In trying to polish the disks, Harshaw fractured two of the crystals as they learned the new techniques necessary. Once the crystals were finished, the concept of HEIST was tested by bombarding them with precise particle beams at UC Berkeley's Bevalac accelerator. The tests provided confidence that HEIST would be able to resolve the isotopes, and the Caltech scientists and engineers began to build the full instrument. As the CES engineers had long known, scientific instruments often present unique engineering problems, which demand unique solutions.

At one point in HEIST's gestation, CES manager Norm Keidel found himself managing a rather peculiar fishing expedition with Schindler. Buffington and Schindler had developed a cooling system for HEIST that relied on water boiling off into space to carry heat away from the instruments. To test the cooling system chamber under extreme conditions of pressure, the engineers had to lower the system into at least 35 feet of water. Keidel and Schindler ended up bobbing about in a borrowed rowboat off a San Pedro pier, monitoring the unit below. They successfully made the critical tests, development forged ahead, and by early 1984 HEIST was ready.

On May 13, 1984, Tiny Tim again sits on the launching pad holding HEIST aloft as the Caltech scientists and engineers run their final checks. Again the parachute is attached; again a mild, muggy breeze jeopardizes the launch. But the breeze dies, and the weather turns perfect. HEIST's instruments function perfectly too, but when the balloon technicians run their tests of the ballast system, they discover a new surprise. One of the hoppers has to be soundly thumped before it will release a smooth flow of steel shot, perhaps because the shot has become packed too tightly. Since nobody will be available to

thump the hopper at 20 miles above the earth, the technicians decide it best to replace the hopper. It isn't the first time a hopper has ever proven balky, but the Caltech scientists hope it's the last for this mission.

At 6:00 pm, Schindler gives his go-ahead, and so do the meteorologists. Above, the NASA chase plane circles, ready to control the ballast and eventually, to trigger the release of the payload to parachute to earth. A small truck carrying a large wooden crate makes its way toward Tiny Tim, and the balloon, now a huge wad of silvery plastic, is payed out of the crate along the ground cloth. The balloon is attached to the top of HEIST's parachute. Soon a large truck fitted with huge red cylinders arrives with the helium. The workers thread two large filler nozzles into the plastic ducts in the body of the balloon. They hold the nozzles aloft; the balloon is ready to be inflated. The valves on the truck are opened.

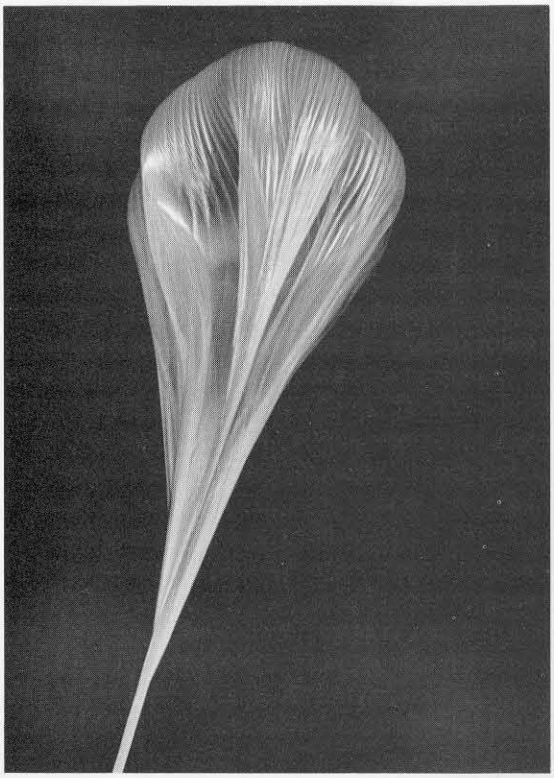
With a powerful hiss, the filling begins. The balloon begins to take shape, as the flow of helium creates a swelling, silvery bulb. The growing balloon is held down at one end by a roller attached to a truck, which inches toward Tiny Tim as the balloon swells and rises higher. After 30 minutes, the hissing suddenly stops. The balloon has been filled with about $10,000 worth of helium, but it remains only partially expanded. Not until it reaches the upper reaches of the atmosphere will the near vacuum allow it to blossom to its full 300-foot diameter.

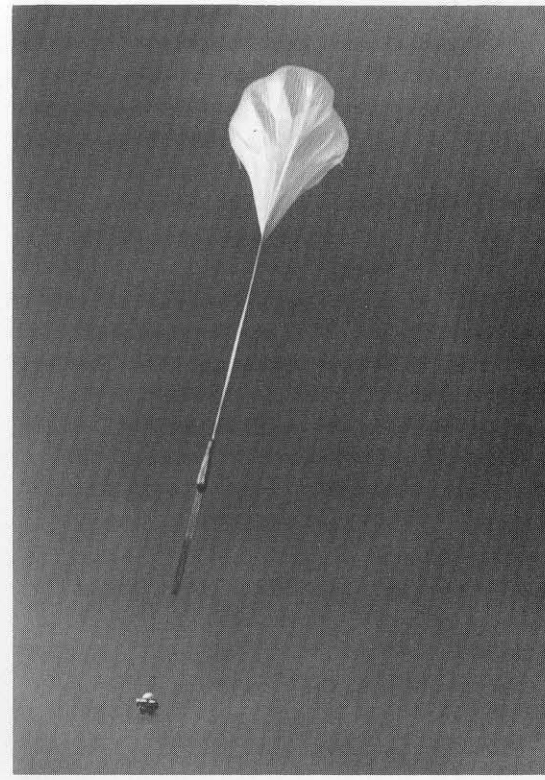
Abruptly, the roller flips back, and like a gigantic shimmering jellyfish, the balloon undulates violently upward to its full 500-foot height, towering over Tiny Tim. The crane starts forward, and with a loud click opens its jaws and scoots away. Without hesitation, the balloon vaults into the cloudless, blue sky, bearing its 3,600-lb. payload smoothly upward at 600 to 700 feet per minute. It is 7:18 p.m., Central Daylight Time on May 13. Schindler crouches at the edge of the launching pad, coolly watching the balloon rise, his ear to a walkie-talkie. HEIST has survived the launch beautifully. After brief congratulations, the scientists return to the hangar to begin the constant two-day vigil over the instruments.

Watching the monitors and printouts, they

Only partially inflated, the balloon is ready for launch.

The balloon sails upward at 600 to 700 feet per minute, bearing HEIST into the troposphere.





follow HEIST's progress as it rises through the critical region of the troposphere, where -70° centigrade cold slows its ascent. The instrument is turned on about one hour into the flight, and a tuning up process is begun. After about two hours, however, the balloon breaks through into the warmer -20° stratosphere, and rises quickly to its maximum altitude of 120,500 feet.

The third hour into the flight, as HEIST drifts northwest toward Fort Worth, the scientists complete the tuneup and continue recording data, which stream in at a high rate. During the entire flight, the instrument will gather some 450,000 impacts from cosmic rays. In fact, so heavy is the data flow that the scientists issue a series of radio commands to HEIST to raise the threshhold at which it triggers, in order to catch only the most interesting particles — the heavier ones. They fear that the high data rate may exhaust the capacity of the onboard tape recorders, and if the balloon drifts out of telemetry range, useful data may be lost.

After meandering over Fort Worth for several hours, HEIST drifts south by southwest over central Texas. Eventually, a line of thunderstorms approaches from the south, threatening the landing. So, at 12:04 p.m. on May 15, after 38 hours at its operating altitude, the chase plane triggers the balloon's release, and HEIST parachutes to earth. The landing — on the treeless, wide-open spaces belonging to a cooperative farmer — is as successful as the flight. The instruments and even the fragile sodium iodide plates are undamaged.

The scientists have now begun analyzing the data, which at first look appear excellent. Next summer, at an International Cosmic Ray Conference, they will report on this first successful test flight.

The story of HEIST, however, has only just begun. Next year, the instrument will be recalibrated at the Bevalac accelerator and possibly fitted with another more sensitive Cerenkov counter that will allow HEIST to measure the isotopes of lighter elements, including beryllium, carbon, and oxygen. If all goes as planned, 1986 may see an enhanced HEIST again rise into the stratosphere.

Ultimately, the Caltech researchers hope that the new technology of HEIST will lead to a version to be launched aboard the Space Shuttle or on a space platform. There the much longer exposure times would allow the gathering of data that would add a useful volume to the exotic chronicle of cosmic ray physics.

But whatever future success this remarkable device experiences will be traced back to that first triumphant flight high over Texas in the spring of 1984.□