A search for ultra-high-energy gamma rays at the South Pole

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In the same year that Amundsen reached the South Pole, an Austrian physicist, Victor Hess, discovered that the outer layers of the Earth's atmosphere are continuously being bombarded by a rain of charged particles called cosmic rays. In yet another of many attempts which have been made in the ensuing years to pin down the origin of this important component of extraterrestrial radiation, a new instrument was set up at the South Pole during the 1987–1988 austral summer.

Recently it has been discovered that some X-ray binary systems (such as Cygnus X-3 and Vela X-1) emit gamma rays with energies greater than 100 terraelectronvolts. The gamma rays arise from the decay of neutral π-mesons which in turn are produced by the interaction of energetic protons with gas in the region around the X-ray binary. These protons—the grandparents of the gamma rays—are accelerated in the complex electric and magnetic fields associated with the neutron star and accretion disc of the binary system. Only a fraction of the protons interact, and those which escape are injected into the interstellar medium to become "cosmic rays." It is more fruitful to study the gamma rays as a clue to cosmic ray origin, rather than to look at the incoming proton beam itself: unlike the charged protons which "random walk" as they are scattered by magnetic fields in the galaxy, the gamma rays travel in straight lines. This makes it possible to identify point sources, provided the exceedingly small gamma-ray signal can be picked out from the more abundant and isotropic cosmic-ray background.

Detection of high-energy cosmic and gamma rays is rather complicated. Because of the very low flux above 100 terraelectronvolts (approximately 1 per square meter per year), a very large area detector is required, and one must make use of the fact that both the cosmic and gamma rays generate cascades containing many thousands of particles when they interact in the Earth's atmosphere. At the altitude of the South Pole, the particles are traveling at the velocity of light in a disk about 50–100 meters in radius and a few meters thick (figure 1). In the Bartol/Leeds telescope, sixteen 1-square-meter blocks of plastic scintillator are spread out over about 7,000 square meters (figure 2). The disk arrives at each detector at a different time (see figure 1) and, by measuring the relative arrival times, it is possible to deduce the arrival direction of the incoming cosmic ray or gamma ray to within about 1°. The precision of measurement necessary at each accurately known detector position is about one billionth of a second.

The South Pole provides a unique location for studying X-ray binary systems which are candidate sources of ultra-high-energy gamma rays: many more are visible than from northern latitudes and, most importantly, every source remains at constant elevation. This latter feature is particularly crucial because most of the sources detected so far appear to be sporadic emitters of radiations. Additionally, the height of Amundsen-Scott Station (equivalent to 3,200 at warmer latitudes) means that the cascades of particles are close to their maximum size. Thus, the energy threshold of the telescope is relatively low. An added bonus that was not anticipated when this project began

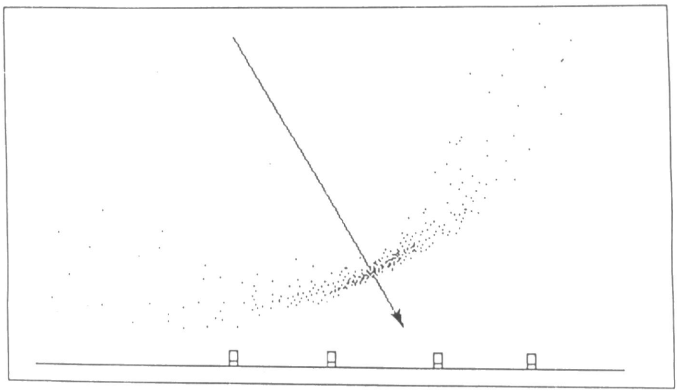

Figure 1. A schematic representation of the particle cascade (dots) about to hit four detectors. The arrow shows the direction of the incoming cosmic ray or gamma ray which has initiated the cascade.

was the birth of a rare supernova. Supernova SN1987A is in the Large Magellanic Cloud, which is only 21° from the polar zenith. The median energy of events detectable from that direction in our experiment is about 100 terraelectronvolts. SPASE (South Pole Air Shower Experiment) is by far the world's most sensitive detector of ultra-high-energy gamma rays.

SPASE began acquiring data just before Christmas 1987. Data from tapes brought out at station closing have now been analyzed, but at this writing, no signal from the supernova has yet been detected. The experiment is continuing to operate with over 90 percent on-time, a level of efficiency which is impressive even at more hospitable sites. At the present time, only about 2 percent of the data can be transmitted during the winter, so the collaborators at Bartol and Leeds are preparing to cope with an influx of about four gigabytes of data late in 1988.

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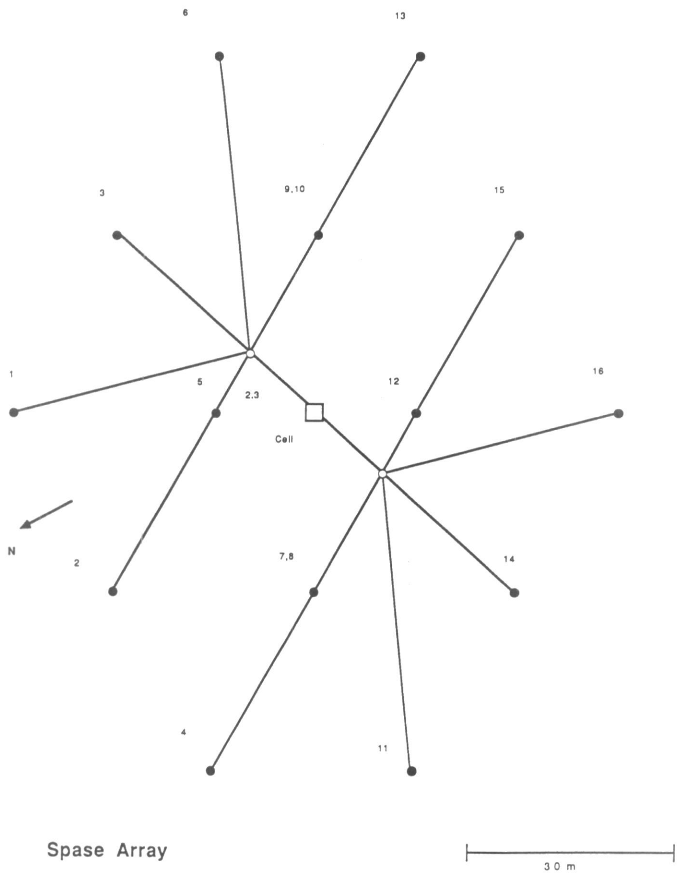

Figure 2. The arrangement of the 1-square-meter detectors in the ultra-high-energy gamma-ray telescope at South Pole Station. High bandwidth cables bring the signals to the central recording cell where amplitude and relative arrival time measurements are made. (SPASE denotes South Pole Air Shower Experiment. m denotes meter.)