between acting as a fixed-target proton-synchrotron and a collider. A fixed-target run was set for June, and the physicists on these experiments, who were not enthusiastic about changing their plans, demanded delaying the collider run to the fall. Darriulat then wrote a memo to the CERN directors saying that "We shall make fools of ourselves if we further delay the next antiproton run . . ." but to no avail. The next day the decision was announced: the collider run begins 4 October.

In the meantime, analysis of the data gathered in last fall's run has been under way, and some results have already been presented, most recently at the Washington physical society meeting. Although the data gathered by UA-1 are mainly being used to tune up the instrument for the W and Z search, there have been some mildly interesting findings, Rubbia reported. One of these is the observation of an anomalously high probability of events with very large numbers of tracks (also seen by UA-5). This result was obtained with the central detector alone. When data from the calorimeters were thrown in, the physicists discovered that those events in which a large fraction of the total energy was due to particle motion perpendicular to the beam direction (transverse energy) were also characterized by a large number of particles, each carrying a small part of the total transverse energy. This result is in contradiction to the naïve expectation that large transverse energy events should be traceable to quark-antiquark interactions that produce a small number of highly energetic particles. The latter phenomenon is termed jets and is one of the ways physicists had hoped to study the strong nuclear force at high collision energies. Now it appears jets will be embedded within these showers of low transverse energy particles and hence more difficult to isolate.

With several months to iron out the numerous little flaws that still remain in the detectors, the UA-1 and UA-2 groups should be primed for the W and Z search this coming fall. One of the big questions is how well the SPS will work as a proton-antiproton collider. The figure of merit for colliding beam machines is the luminosity, which roughly corresponds to the brightness of a light beam. If the luminosity is low, as it was last fall, CERN would have a much more serious situation on its hands than simply a dirty detector.

In a recent meeting of SPS users, Giorgio Brianti, one of the CERN directors, recalled that the highest luminosity achieved last year was 200 times lower than the design figure of 10^{30} cm^{-2} sec^{-1} and the average was ten times lower still. Brianti's projection for 1982, taking into account several improvements in the antiproton production and accumulation machinery, was for an average luminosity of 10^{28} *if* the SPS works reliably. Since it requires 1 day to generate the antiproton beam, it does not take many lost beams to depress the average luminosity even if the peak value is high. Rubbia told the physicists at the Washington meeting that about 10 W's and 1 Z would be produced per day at a luminosity of 10^{29}. On other occasions, Rubbia has argued that no fundamental changes need be introduced into the SPS or the antiproton production and accumulation machinery to reach a peak luminosity of 10^{29}, about three times higher than Brianti's more conservative estimate.

All in all, these seems to be a good chance of seeing candidate W events by the end of the year, but whether there will be enough to provide persuasive statistical evidence remains in considerable doubt.—ARTHUR L. ROBINSON

A Hole in the Milky Way

Beyond the star clouds of Sagittarius there is an energy source like nothing else in the galaxy

For the record, astronomers like to call the thing they have found at the center of our galaxy a "compact source." But, in fact, many of them now believe it is a black hole with as much as one million times the mass of the sun.

There is no absolute proof—the galactic center is 30,000 light-years away and hidden from us by thick lanes of interstellar dust and gas; there may never be absolute proof—but data gathered over the last 5 years at radio, infrared, and gamma-ray wavelengths have made the case for a black hole compelling. At a recent symposium on the galactic center, held at the American Physical Society meeting in Washington, D.C., Richard Lingenfelter of the University of California, San Diego, captured the general tone when he asserted, "Something truly extraordinary is happening there." Marvin Leventhal of Bell Laboratories asked rhetorically, "Does the evidence call for a unique object at the galactic center?" and drew no objection from his colleagues when he concluded, "Yes."

The galactic center, lying in the constellation of Sagittarius, is among the brightest radio sources in the sky. (In fact it was the first extraterrestrial radio source ever detected, in 1932.) But for years it remained a mystery. The resolution of radio telescopes was too coarse to say much about it. Optical telescopes might have done better, but their view of the center is blocked by clouds of gas and dust in the galactic plane. And Earth's atmosphere is opaque to every other wavelength.

During the 1970's, however, new clues began to emerge from the theory of quasars. It seemed increasingly certain that these objects are both very far away and exceedingly bright. Some of them are probably 100 trillion times as luminous as the sun—a thousand times as luminous as the entire Milky Way galaxy. Barring some unknown principle of physics, this prodigious energy output is best explained by postulating a massive black hole embedded in an otherwise normal galaxy.

Gas and dust spiraling into such a hole from the galaxy's central regions would be compressed and heated, converting much of its mass to radiant energy before finally falling in. Detailed calculations showed that this is an exceedingly efficient way for mass to convert into energy—far better than fusion or fission. Given a sufficiently large hole, perhaps a billion times the mass of the sun, the energy output could indeed approach quasar levels.

The model also explains the long jets of matter that shoot out from many quasars. As matter falls toward the hole its angular momentum tends to sweep it into a disk. As it spirals inward the temperature and pressure mount; eventually, some of the material squirts out the axis of the disk as relativistic jets. A spinning

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black hole would cause the disk to wobble and produce spiral jets, rather as a lawn sprinkler produces spirals of water. Such jets are in fact seen.

Other luminous objects also seem to fit into this scheme. The Seyfert galaxies, for example, are galaxies that seem normal except for their extremely bright cores. Although they are much closer than quasars, and much less luminous, their spectra look very similar. Perhaps they just have smaller black holes in the middle. Or perhaps the Seyferts are dying quasars, whose massive black holes that have swept up so much material from the central regions that little is left.

Either way, it is tempting to extrapolate from quasars and Seyferts to normal galaxies like our own. Perhaps every galaxy contains a central black hole. Maybe the holes somehow formed very soon after the Big Bang, each one swaddling itself in cosmic gas that would later condense into a galaxy. Or maybe the galaxies formed first, with their central stars clustering so densely that they eventually collided, coalesced, and collapsed under their own gravity.

Only recently, however, has it been possible to put these ideas to an observational test in our own galaxy. Infrared radiation, as it happens, does penetrate interstellar gas and dust. It is also absorbed by water vapor in the earth's atmosphere, but since the mid-1970's the National Aeronautics and Space Administration has been flying a small telescope aboard the Kuiper Airborne Observatory, a modified C-141 transport aircraft that can cruise for hours in the dry air above 10,000 meters. And still more recently, a series of large infrared telescopes has begun operation at high, dry mountain sites such as Mauna Kea in Hawaii.

Ian Gatley of the United Kingdom Infrared Telescope at Mauna Kea told the APS meeting that these instruments have revealed a thin haze of silicate dust around the center of the galaxy. But instead of permeating the entire central region the dust seems to be distributed in a ring. "It is not overstating the case to say that the galactic center itself is almost devoid of dust," he said.

Even more interesting is the temperature of the dust, as derived from its infrared brightness: the isothermal contours circle the exact center of the galaxy like a bull's eye. Although the temperatures involved are low, a few hundred degrees Kelvin, the total luminosity is huge—several hundred million times the luminosity of the sun.

It may be, as some astronomers have suggested, that all this energy is coming from a compact cluster of hot young stars, said Gatley. "But you would need about 1000 young stars jammed into a volume about one light-year across," he pointed out. "It is very hard to explain the origin of such a cluster.

"I put it to you," he concluded, "All the radiation is coming from here [the center of the bull's eye]; the source is exceedingly luminous; it cannot be attributed to stars; and it comes from a region unique in the galaxy."

In 1979, the National Radio Astronomy Observatory (NRAO) completed construction of the Very Large Array of radio telescopes in New Mexico. This Y-shaped array, with its 27 movable antennas, provides a far higher resolution than ever before possible at radio frequencies. Its imagery of the galactic center, as presented to the Washington meeting by NRAO's Robert L. Brown, shows a remarkable spiral-like pattern about three light-years across, centered on an exceptionally small and luminous source. As it happens, this source lies precisely at the center of Gatley's bull's eye.

The gas in the spiral pattern appears to be flowing outward from the central source at the rate of about one solar mass per 1000 years and at velocities in excess of 350 kilometers per second, said Brown. On one arm of the spiral the gas is approaching the earth, and on the other arm it is receding. This makes sense, he said, if the source is emitting a pair of opposing jets that wobbles with a precession period of about 2300 years.

The source itself, meanwhile, varies strongly in intensity from day to day but varies very little on a time scale of minutes. Since there is no way for dynamical effects to move faster than light, Brown deduces that the source must be between ten light-minutes and one light-day across—in other words, larger than the earth's orbit, but not much bigger than the solar system. "We conclude that the central object must be gravitationally collapsed," he said. "That is, a black hole."

At the other end of the spectrum, the hard x-ray and gamma-ray emissions from the galactic center are also absorbed in the atmosphere. But starting in 1977 a joint Bell Laboratories/Sandia Laboratories group has launched three scientific balloon flights over Alice Springs, Australia, specifically to study this region. The upshot was the discovery of the brightest gamma-ray source in the galaxy. Moreover, fully one-half the energy was in the form of 511-kiloelectron-volt photons from the annihilation of electrons and positrons. The result was confirmed from orbit in 1979 by Allan S. Jacobson of the Jet Propulsion Laboratory using NASA's High Energy Astronomical Observatory 3 (HEAO-3).

NRAO

At the core

The core of the galaxy, as seen at radio wavelengths by the Very Large Array. Spiral jets stream outward from the bright central knot—a black hole?

When HEAO-3 looked again in 1980, however, the intensity had dropped by a factor of 3, and by 1981 the source of the gamma rays had turned off. Presumably it will one day turn back on again, but already, says Bell Laboratories' Leventhal, the variation implies a source no more than half a light-year across.

Lingenfelter and Reuven Ramaty of NASA's Goddard Space Flight Center believe that the annihilation radiation comes from electron-positron pairs produced in the collisions of high-energy gamma rays with one another. Their calculations indicate that other processes are either not efficient enough to produce such a high fraction of 511-keV photons in the spectrum, or else would produce additional emissions that are not observed. On the other hand, Lingenfelter and Ramaty believe that the production region has to be no bigger than about 10 million kilometers—a fraction the size of the earth's orbit. Otherwise the intensity of background gamma rays would be too high.

"These requirements are remarkably consistent with models of an accretion disk around a black hole," said Lingenfelter. In these models the high-energy gamma rays needed to produce the electron-positron pairs would be emitted from the hot plasma at the innermost fringes of the disk. Unfortunately, there is no way of knowing whether the gamma rays are being emitted uniformly in all directions, or are somehow being beamed. So observations are consistent with a black hole anywhere from 100 times to one million times as massive as the sun.—M. MITCHELL WALDROP