that at least some of the effort to develop new technologies can be done in conjunction with research on human diseases. She cited, for example, the powerful physical mapping technique, pulsed field gel electrophoresis, developed by Charles Cantor and his colleagues at Columbia University. The technique had never been tried on human DNA until Wexler's group offered them DNA from chromosome 4, the location of the still-elusive Huntington's disease gene.

The critical organizational question the committee grappled with was whether the new program should establish research centers and, perhaps more important, fund their construction. The answer is, yes, the committee concluded, if the program's tight deadlines and ambitious goals are to be met.

"Realistically, that is the only way programmatic progress will be made," said Olson, who added that the grants funded by NIGMS this year are probably the best the group will see, "but they simply don't add up to a program." And convincing universities to take on a new center, said Watson, will "require the carrot of new space"; thus, the need for construction funds.

These centers, which might focus on physical mapping of the nematode, for example, should not be created de novo, the committee agreed, but should grow up around the best labs in the country already doing this work. The problem is, there just aren't that many of those embryonic centers around, which is a stark reminder of just how few experts there are at this stage.

The challenge, the committee members agreed, will be to create true intellectual centers and not just paper entities. As Bruce Alberts of the University of California asked: "How do you establish centers without the inertia we fear will develop and the wasted resources?"

Committee chairman Zinder established a working group to look at the number and size of centers, their areas of expertise, and other questions. Zinder also set up working groups on training, databases, and ethics.

Ethics will be a central concern of the genome office, said Watson."Some very real dilemmas exist already about the privacy of DNA. The problems are with us now, independent of the genome program, but they will be associated with it. We should devote real money to discussing these issues. People are afraid of genetic knowledge instead of seeing it as an opportunity."

The committee meets again in June, but the working groups may be called on before then as Watson and Wyngaarden prepare for this spring's budget hearings, when Congress will undoubtedly want to know what is in store for the year ahead.

■ Leslie Roberts

Pruning the Thickets of Cosmic Speculation

Cosmology currently suffers from too much theory and not enough data; the new Center for Particle Astrophysics could help

For more than a decade now, the nascent field of particle astrophysics has grown like a garden gone wild. Cosmic strings, cosmic inflation, particles of invisible "dark matter"—whole thickets of speculation have sprung up around the events of the Big Bang as physicists and astronomers have struggled to understand how the dynamics of particles *then* could have shaped the universe we see *now*.

During the next 2 or 3 years, however, that garden is due for a severe pruning. Researchers are beginning to put cosmological speculations to the test with experiments in a variety of areas, notably dark matter, gravity waves, and the cosmic background radiation.

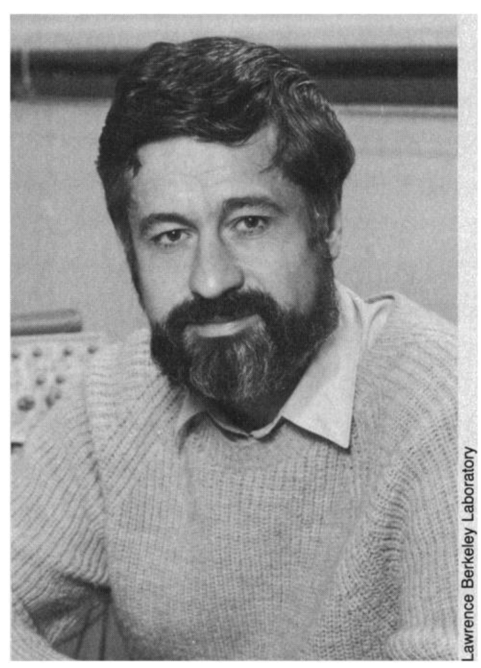
Perhaps most significantly, these experimental efforts have now received official recognition from the National Science Foundation in the form of a Center for Particle Astrophysics at the University of California, Berkeley. With 25 member scientists and a budget of $10.6 million over the next 5 years, the Berkeley center will try to facilitate and coordinate as many of the new projects as possible. Moreover, despite the inevitable concerns about siphoning off funds from *non*-center projects, the center has generally been greeted with enthusiasm: "It's a very healthy step," says Princeton University's David Spergel, who was a principal in an unsuccessful bid to locate a similar center at Princeton. "It recognizes the emergence of a subfield and it emphasizes *data*."

At least initially, says director Bernard Sadoulet, the center will focus on the problem of dark matter, which comprises up to 90% of the mass in the universe and which is detectable only by its gravitational effects on galaxies and clusters of galaxies.

Current conventional wisdom has it that dark matter can most plausibly be explained as a universe-wide haze of elementary particles left over from the Big Bang. One reason for thinking so is that the physicists' theories of grand unification and supersymmetry predict a variety of heavy neutrinos, "axions," and "photinos" that would serve quite nicely. Each of these hypothetical particles would possess a small mass, so as to produce the gravitational effects; and each of them would interact very weakly with ordinary matter, so as to remain invisible. (Thus their generic name: Weakly Interacting, Massive Particles, or WIMPs.) Another reason is that computer models suggest that the gravitational dynamics of such a particle haze would produce a distribution of galaxies and clusters in the universe very much like the one we see. All that is required is that the particles come out of the Big Bang moving much slower than the speed of light—or in a word, that the dark matter be "cold."

Plausible or not, however, this is precisely the kind of model-making that Sadoulet and his colleagues at the Berkeley center want to test. They are currently planning several lines of attack. Some highlights:

■ **Direct detection of dark matter particles.** This is the center's highest priority and most formidable technological challenge, says Sadoulet. Even with an estimated flux of roughly 1 million dark matter particles per square centimeter per second, a 1-kilogram detector would experience roughly one event per day. Moreover, each event would only deposit some 1000 electron



Bernard Sadoulet. *Dark matter is the center's highest priority and toughest challenge.*

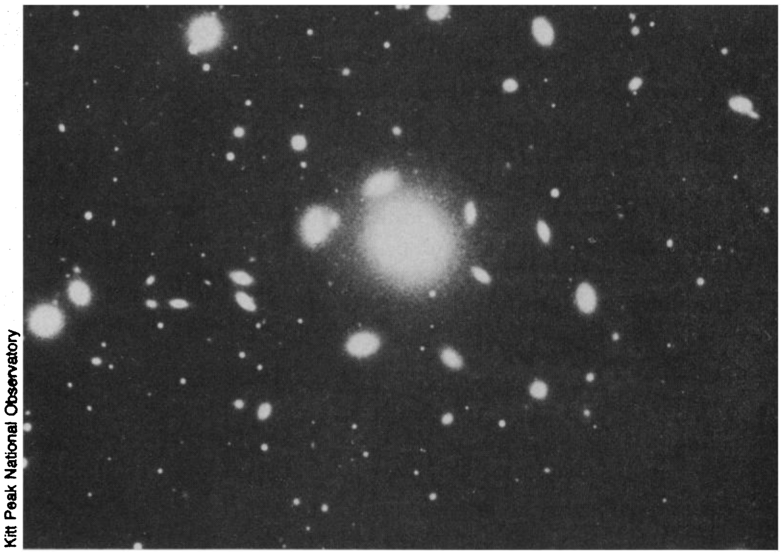
volts (1 keV) of energy. So a WIMP detector has to be able to register such a signal without being swamped by background noise.

In the past several years that challenge has led various research groups to propose at least half a dozen innovative detector designs, all of which are now well along in development. At least for now, however, the Berkeley center will have to focus its resources on just a few of them.

For example, one idea being pursued by Sadoulet himself is to take a crystal of silicon, put it in a deep mine where the cosmic rays cannot get at it to produce spurious signals, and then cool it down to liquid helium temperatures. Not only does this last step minimize thermal noise, but it maximizes silicon's specific heat: the rise in temperature produced by a given input of energy. So if and when a WIMP interacts with one of the silicon atoms, the recoil will noticeably raise the temperature of the block. The amount is still tiny, some 20 millikelvins. But Sadoulet and his colleagues are already working on thermometers that they believe can measure such quantities.

A related effort is being headed by Stanford University's Blas Cabrera, who is also a member of the new center. Cabrera and his colleagues are trying to detect the recoil energy of a WIMP event in silicon immediately after impact, before the energy diffuses into general thermal vibrations of the crystal lattice. What happens is that the recoil first produces a "phonon," a quantized vibration of the lattice. The Stanford researchers believe that they can detect such a phonon as it strikes the surface of the crystal, using films of superconductor deposited on the surface by the standard photolithography techniques of the microelectronics industry. If so they will be able to determine the location of the WIMP interaction in the crystal as well as its energy, which will be a great help in rejecting spurious background events.

■ **Anisotropies in the 2.7 K microwave background radiation.** In essence, this radiation is the afterglow of the Big Bang. One of the major open questions about it is the existence of subtle variations in the temperature from point to point in the sky. Known technically as "anisotropies," these variations would presumably correspond to equally subtle variations in the density of the cosmic plasma at the time the photons were emitted, about 300,000 years after the Big Bang. The density variations, in turn, would presumably correspond to the initial clumps of matter that later gave rise to galaxies and clusters of galaxies by gravitational contraction. And since the pattern of clumping is one of the best ways of telling one model of galaxy formation from another, some actual measurements of the magnitude and distribution of anisotropies on the sky would do a lot to weed things out.



Kitt Peak National Observatory

The cluster in Coma Berenices. *Roughly 90% of the mass is utterly invisible.*

At the moment, the best upper limits on the temperature anisotropies stand at one part in 10^4 or even a few parts in 10^5, depending on the precise wavelength and size of the patch of sky being observed. Within the next year or so, however, those limits should fall to one part in 10^5 or better. The Cosmic Background Explorer satellite, due for launch next spring, should do at least as well for fluctuations on angular scales larger than about 10 degrees. And the Berkeley center is already sponsoring a group of ground-based astronomers—as just one of several competing groups—who are developing a balloon-borne cryogenic detector that should achieve sensitivities of 10^{-5} or better on angular scales of a few degrees.

Unfortunately, it is not yet clear whether any of these measurements will challenge the cold dark matter model of galaxy formation: it predicts anisotropies of only a few parts in 10^6. Achieving that level of sensitivity could require several years more work. However, these experiments *will* pose a crucial test for models that rely on the bizarre phenomenon known as cosmic strings.

Cosmic strings are exceptionally thin, exceptionally heavy vortices of energy predicted by certain of the physicists' grand unified theories. If real, they would have condensed out of the superheated cosmic plasma during the first instants of the Big Bang, filling the universe with a dense network of threads and loops. The loops, in particular, would have been massive enough to pull in clouds of ordinary matter around themselves by gravity, and thus to serve as "seeds" for galaxy formation. Indeed, computer models of the resulting distribution of galaxies are at least as realistic as the ones provided by the cold dark matter model.

The cosmic background becomes a test of the string model because strings moving through the early universe would have produced a patchwork of subtle, but unmistakable discontinuities in the radiation. The Berkeley experiment, for one, should either be able to see the effect, or rule it out in the near future.

Meanwhile, cosmic strings should also be detectable via another type of radiation from the early universe: gravity waves.

■ **Cosmic strings and gravity waves.** The idea here is that the strings would have come out of the Big Bang in a furious state of vibration, and, being so massive, would have radiated away virtually all of their energy in the form of gravity waves. By now, unfortunately, the cosmic expansion would have stretched out most of this radiation into wavelengths measured in light-years, making them utterly invisible to any laboratory experiment. But they need not be invisible to an experiment provided by nature: the millisecond pulsars.

About a half-dozen of these objects have been discovered since the first one was found in 1982. They all rotate at roughly 500 to 1000 times per second, and as timepieces they have turned out to be considerably more accurate than atomic clocks on Earth. Using one as a gravity wave detector is fundamentally just a matter of monitoring its pulses over time: if a long-wavelength gravity wave were to pass, its effect would be to push the pulsar signal in and out of phase on time scales of a year or more.

In practice, of course, the sensitivity of the measurement is limited by various sources of background noise in the receivers and even in the galaxy itself. Nonetheless, the 6-year record of the first millisecond pulsar has turned up nothing—a fact that is already beginning to make cosmic string theorists nervous. And the push is on to do better. Berkeley's Donald Backer, who discovered that first object in 1982, will lead a center team trying to improve the sensitivity by roughly an order of magnitude.

■ **M. Mitchell Waldrop**