to bring the partners together. Their joining forms the binding site that enables the protein complex to attach to specific DNA sequences on the genes it regulates.

Researchers have been stymied, however, in their efforts to identify the genes that the *myc* protein might regulate because they were unable to find either a protein partner for it or the specific DNA sequences to which it binds. That's the problem the Eisenman group now appears to have solved.

The *myc* protein may have been so hard to study, Eisenman says, because the isolated molecules have a strong tendency to interact with each other, forming aggregates that preclude their interacting with other proteins or with DNA. The Seattle workers got around this problem by using a 92–amino acid segment of the protein containing the helix-loop-helix and leucine zipper motifs instead of the whole protein. Keith Blackwell, who works in Harold Weintraub's lab at the Hutchinson Cancer Center, was then able to identify a specific DNA segment to which that sequence binds. But the binding was weak, Eisenman says, which is an indication that another protein cooperates with the *myc* protein to form a DNA recognition site.

So the next step, undertaken by Elizabeth Blackwood, a graduate student in Eisenman's lab, was to find that protein. She again used the 92–amino acid *myc* segment, this time to screen a library of protein-producing mammalian DNA clones. It was a tedious task. Out of 1 million clones screened, she found just two producing a protein that bound to the *myc* protein segment. Both turned out to be producing the same protein, and the Eisenman group has now sequenced the corresponding DNA clone. The protein encoded by the gene, which the researchers are calling *max* (for *myc*-associated X), is a new one; the sequence does not appear in any of the data banks. It bears a partial resemblance to the *myc* protein, however, especially in the helix-loop-helix and leucine zipper regions. "That's exactly what you would expect for something that would bind the *myc* protein," Eisenman says. "We think it's possible that we have finally found a binding partner for it."

Participants in the Cold Spring Harbor meeting were enthusiastic about the work because it opens the door to identifying the genes regulated by the *myc* protein and dissecting its normal and pathological roles in the cell. But the work may have a wider significance as well. The method used for finding *max* may also be useful for identifying the binding partners of other gene regulatory proteins, thereby leading to a better understanding of gene control generally.

■ JEAN MARX

Millimeter Astronomers Push for New Telescope

The new facility would give them an unprecedented ability to study star and galaxy formation—but at a cost of $120 million

IN AN ERA OF GRAMM-RUDMAN BUDGET cuts, shrinking research grants, and post-Hubble sensitivities, it takes more than a little chutzpah to propose yet another big science project, especially one in a relatively new field. But that is what a stalwart band of astronomers, led by Robert Brown of the National Radio Astronomy Observatory, has just done. Their plan—to build a complex new telescope for detecting millimeter-wavelength radiation—landed on the desk of Laura Bautz, director of the National Science Foundation's astronomy division earlier this month. All they're asking for is a cool $120 million. That would make their scope, known as the Millimeter Array, the most expensive ground-based astronomical facility yet constructed.

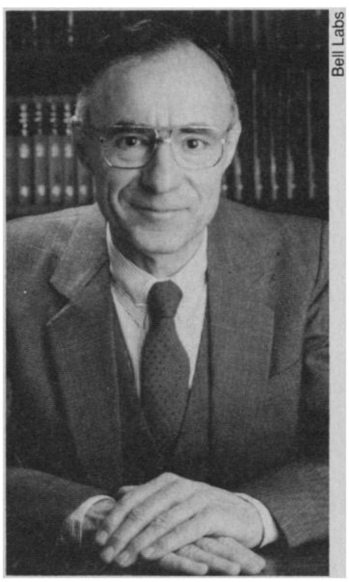
It would be worth every penny, maintains Brown. "Millimeter astronomy tells you about interstellar gas clouds—where they are, what they're made of, and what they're doing," he says. "And since what they spend a lot of time doing is making stars and galaxies, millimeter astronomy provides you with important clues about the birth and evolution of the universe."

Since other forms of astronomy can't provide that kind of information, millimeter astronomy has soared in stature since it burst onto the scene a mere 20 years ago. Before then, the researchers had known little about the existence, composition, location, and behavior of interstellar clouds, which are invisible at most wavelengths. What they did know came through the centimeter "window" onto the electromagnetic spectrum, which was partly opened in 1951 when Harvard astronomers Edward Purcell and Harold Ewen detected the 21-centimeter spectral line emitted by atomic hydrogen with an antenna protruding from the Lyman Laboratory.

By the mid-1960s, when centimeter astronomy was in its heyday, researchers were laboriously mapping the clouds' hydrogen distribution. Their objective was to assemble supposedly complete radio maps of interstellar gas clouds, which were then published in the *Astrophysical Journal*. But they little suspected that a revolution that would improve the resolution of the maps by orders of magnitude was just around the corner.

At the time, millimeter astronomy was not in high repute. During the 1960s, the National Radio Astronomy Observatory (NRAO), which is headquartered in Charlottesville, Virginia, had built a 36-foot telescope in the millimeter range on Kitt Peak in Arizona. One goal was to use the facility to detect the continuum radiation created by such things as supernovas and radio galaxies. But the telescope, which was completed in 1967, proved to be a disappointment—at first. It had been troublesome to build, it never reached its design specs for accuracy, and it turned out to be difficult to use.

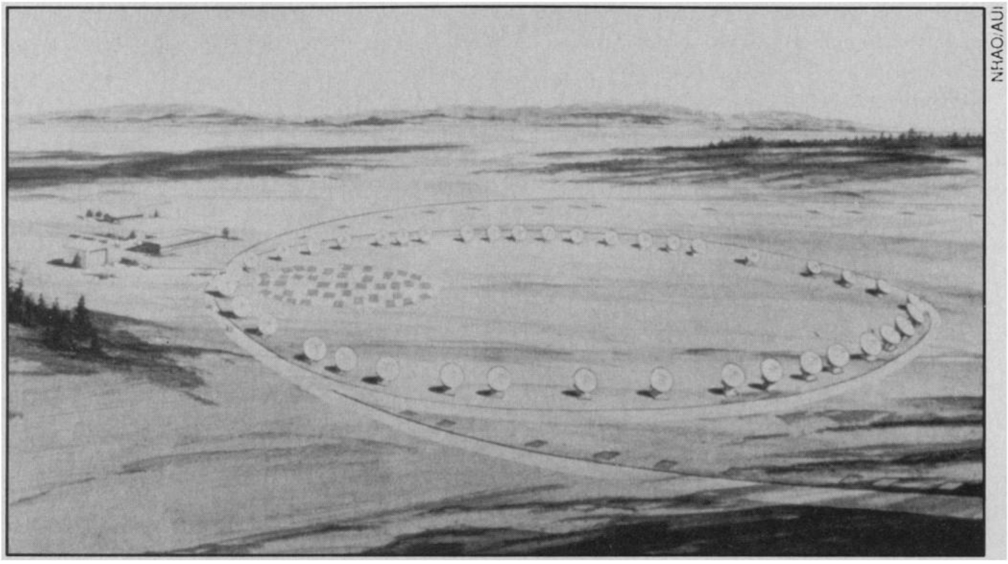
Most frustrating of all, at the outset there was little scientific payoff. The continuum sources were unexpectedly weak, and their study failed to yield the surprises usually turned in by a major new instrument. Things were so disappointing that for several years the Kitt Peak telescope was unique among U.S. telescopes in that it was easy to get time on.



Millimeter astronomy pioneer. *Arno Penzias saw a new window into space to exploit.*

But that was before Bell Labs scientist Arno Penzias entered the picture. In the late 1960s, Penzias was impressed by recent discoveries of certain interstellar molecules. They had been newly observed through the centimeter window by means of the spectral bands related to the low-energy quantum transitions that result when molecules are stretched, bent, or rotated. He began to suspect that the millimeter region—in which the bulk of such transitions occur—harbored vast potential as an astronomical tool.

"For me," Penzias says, "the most interesting parts of the night sky are the places where the stars aren't. At the time, we knew there must be huge dust clouds out there, but didn't know what the stuff was made of and how much of it there was. I would have thought astronomers would have been really curious about it, instead of just paying attention to the little blinking lights. Those dust clouds are the progenitors not only of stars but also of the earth and of what we are made of, and I felt they really deserved more study. And here was this underutilized part of the spectrum, which might be broken open with a little effort. So I began to thump the drums for millimeter astronomy."



A compound eye on space. *This artist's simulation shows the 40 antennas that will form the proposed Millimeter Array—if it is built.*

Penzias recruited two collaborators, Robert W. Wilson and Keith Jefferts, both of Bell Labs, and prepared a run on the Kitt Peak telescope in May 1970, to look for the characteristic 2.6-millimeter rotation line of carbon monoxide. The researchers chose that spectral band because they thought that carbon monoxide would be relatively common in interstellar clouds and the signal therefore relatively easy to detect with new technology that the Bell workers had developed for the job.

But even so they didn't expect immediate success. When the Bell group began their observations, there were no online computers that could immediately process the signals picked up by a telescope. The only thing that could be seen on the oscilloscope screens that displayed the signals radio astronomers detected was a series of points corresponding to a two-second average of the signal at each channel frequency plus the background noise from the receiver and atmosphere. The trio expected to have to collect and integrate signals for days before seeing a result.

But when they first switched on the receiver and tuned in to Orion A—the great nebula—several points in the middle of the screen jumped noticeably. "Ah!" Wilson joked, "there's the CO!"—fully expecting the bump to be due to faulty equipment. It wasn't. In June 1970, the team sent a letter to the *Astrophysical Journal,* summarizing their results in a single-sentence abstract: "We have found intense 2.6-millimeter line radiation from nine galactic sources which we attribute to carbon monoxide."

That sentence hardly suggests the discovery's significance. The 2.6-millimeter carbon monoxide line was to become even more important to millimeter astronomy than the famous 21-centimeter hydrogen line was to centimeter astronomy. Carbon monoxide is widely distributed in galaxies because it is readily formed and difficult to destroy, even by ultraviolet radiation. And since the carbon monoxide line proved to be so easy to detect, it has become an excellent tracer for the presence of interstellar molecular clouds.

But the carbon monoxide line was only the first in a series of molecular spectral lines to be discovered at Kitt Peak. In the next few years other millimeter astronomers discovered dozens of molecules in space. Interstellar clouds were revealed to be the most massive objects in galaxies, often containing hundreds of thousands or even millions of times more mass than our solar system.

And because millimeter telescopes detect radiation of shorter wavelengths than centimeter telescopes, the angular resolution of comparable millimeter telescopes is superior. That meant that the sources could be located and studied with unprecedented precision, making the painstakingly completed centimeter radio maps of the 1960s outdated. Using millimeter telescopes, astronomers could not only find out where the clouds were and what they were made of, but they could also tell what the clouds were doing—whether they were rotating, expanding or contracting, and so forth.

Moreover, millimeter astronomy has even given rise to a new branch of chemistry. Some compounds, such as HCO^+, discovered in 1970 at Kitt Peak at 3.37 millimeters, were first detected in space, and only subsequently and with enormous difficulty created in terrestrial laboratories. Over the decades, the results turned in by millimeter antennas have proved sufficiently intriguing to catch the attention of chemists. The result: astrochemistry.

Moreover, millimeter astronomy has handed astronomers a new key to the structure of the universe. "Previous to millimeter observations," says NRAO's Brown, the project director for the Millimeter Array, "the understanding was that stars form in dense, spherical clouds which are collapsing under their own gravitation, and that star formation occurs first in the cloud center, where the material is densest. The millimeter wave observations showed that the stars formed first not in the centers of clouds but on the outside. That took a very long time to understand. Eventually, theories of star formation were forced to rely on an external trigger, like a supernova, to squeeze in the outside of the cloud, giving rise to a vigorous burst of star formation in a short period of time. So millimeter observations transformed the picture we had of star formation from a quiescent to a violent process. That was quite a shock."

By the end of the 1970s, something fundamental had changed at Kitt Peak's 36-foot telescope: it had become one of the most difficult U.S. telescopes to get time on, sought after by junior faculty anxious to score tenure-winning discoveries.

Despite the great promise of millimeter astronomy, however, this country's commitment to the field remained modest. A few relatively small-scale millimeter telescopes were constructed to complement Kitt Peak's. The McDonald Observatory, for instance, converted one of its radio antennas to a 4.9-meter dish suitable for millimeter observations, while the University of Massachusetts at Amherst constructed a 13.7-meter dish. The NRAO also renovated their Kitt Peak facility in 1983, giving it a more accurate and slightly larger dish, which then became known as the 12 meter. And two multiple element millimeter-wavelength telescopes, which are known as interferometers, have been constructed in California, in Hat Creek and Owens Valley.

Nevertheless, other nations took millimeter astronomy more seriously. In the now classic pattern, a field first opened up in this country was pursued far more avidly abroad. A 20-meter dish was constructed at Onsala, Sweden, a 45-meter dish at the Nobeyama Radio Observatory in Japan, and a highly sensitive 30-meter dish at Pico Veleta, Spain, by a Franco-German consortium called IRAM (Institut de Radio Astronomie Millimétrique). This latter antenna is regarded by many as the foremost millimeter telescope in the world. IRAM has also sponsored an interferometer consisting of three linked 15-meter dishes in France on the Plateau de Bure south of Grenoble.

In 1975, NRAO millimeter astronomers, hoping to catch up, proposed building a major new facility, with a 25-meter dish, on Mauna Kea in Hawaii. Critics complained, however, that the Hawaii location was too expensive. The proposal languished, unfunded, for several years, and was eventually abandoned in 1983. Bitterly disappointed, many millimeter astronomers blamed NRAO for not having chosen a less expensive, continental site early on.

Shortly thereafter, Wilson called a meeting at Bell Labs—from which NRAO scientists were specifically excluded—to hold a post-mortem on the project and decide what to do next. The sentiment was to pursue an aperture synthesis array, similar to the Very Large Array, a photogenic assemblage of 27 radio antennnas that sprawls across the plains of Socorro, New Mexico. Such arrays form images by synthesizing signals collected by numerous small antennas. The effective diameter of the telescope is then that of the whole array, even though the collecting area is much smaller, and the image resolution is much better than could be achieved with a single telescope. The idea was to pursue a similar strategy with small millimeter-wavelength dishes.

The proposal was submitted to the NSF, where a subcommittee recommended that a study be undertaken for such an instrument. The study began in 1984 and it soon became evident that the undertaking was too large and costly to be handled by a single university. So the millimeter astronomy community, despite its earlier displeasure with the NRAO, reluctantly concluded that the observatory should handle the project.

Looking to the clouds. *Robert Wilson was in on the discovery of the 2.6-millimeter carbon monoxide line in space.*

NRAO astronomers worked out an initial design and presented it at a workshop held at Green Bank in 1985. After consultations with the astronomers who would be using the Millimeter Array, the details were ironed out in the following years. The final proposal calls for 40 8-meter antennas with a total collecting area of 2010 square meters that can be positioned in any of four possible oval configurations. This would make the telescope much bigger than the only existing millimeter array in Japan, which consists of five elements, and also larger than the proposed upgrade of the Hat Creek facility, which will be expanded to include nine. As proposed, the new U.S. installation would produce images with an angular resolution of less than a tenth of an arc second and would be about 100 times faster and 100 times more sensitive than IRAM's 30-meter, the best existing millimeter telescope

All this might allow the Millimeter Array to answer some of the most basic questions about the formation of planetary systems, including how frequently it happens, how many planets characteristically form, and what is the chemistry of that formation? Moreover, it could attack basic questions about early galaxy formation. Galaxies form out of collapsing clouds of gas, but what happens inside is cloaked from the view of optical astronomers because the surrounding dust absorbs the light from within and reradiates it in the infrared—which is blocked by the earth's atmosphere. In the case of the extremely distant and therefore oldest galaxies, however, that infrared light is red-shifted into the millimeter window. Studying early galaxy formation therefore requires millimeter astronomy but with a sensitivity and angular resolution not previously possible.

To Brown, however, perhaps the most important accomplishment of the Millimeter Array is that it would put millimeter astronomy on the same footing as other forefront astronomical instruments. "The really important questions you ask in astronomy are rarely answered by one telescope," he says. "Rather, you have to combine the results that you get from a number of different sources—optical telescopes, infrared telescopes, millimeter telescopes, and so forth. And you need the capabilities of each instrument to be comparable. The Millimeter Array will have a resolution slightly better than the Very Large Array, comparable to that of the next generation of infrared telescopes, and comparable to that of the Hubble telescope as originally designed."

NSF's Bautz refuses to speculate on the timetable for consideration of the proposal, which faces a lengthy and possibly difficult review process. Three potential sites, one in the Magdalena Mountains near the Very Large Array and the other two near Springerville, Arizona, have been selected, however, and the proposal asks for funds to start in 1993 and anticipates completion by 1997. The chances of success in a time of budgetary restraint are cloudy. Big Science projects are handy targets for budget cutters: The U.S. House of Representatives recently cleaved another one, the Laser Interferometer Gravitational Observatory, out of the NSF budget (also see *Science*, 7 September, p. 1106).

But with the submission of the Millimeter Array proposal to the NSF, astronomers hope to repeat the historical precedent represented by the Very Large Array. Twenty-five years after the discovery of the hydrogen 21-centimeter line in 1951, astronomers were well along in the construction of that facility, which uses the hydrogen line to image atomic gas in galaxies. The 25th anniversary of the discovery of the 2.6-millimeter carbon monoxide line in space will be in 1995. By then astronomers hope to be on the verge of seeing the first glimmers of millimeter light through the Millimeter Array.

■ ROBERT P. CREASE

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