Astronomy: Tight Budget Gains Stranglehold on Radio Facilities

After the cries that greeted the first announcements of budget cuts died down, many scientists found that by making relatively minor adjustments in financing they could carry on much as usual. Major exceptions were research groups that had plans but not funds for expensive new projects when the cuts came. In astronomy, those doing optical research, although still short of observing time, have been able to start construction on a number of telescopes and are planning several more. Radio astronomers, however, have been unable to obtain funds for facilities recommended 5 years ago and are beginning to fear that the momentum that has attracted talented researchers from engineering and physics into radio astronomy may soon be lost.

In both optical and radio astronomy new research problems—uncovered by recent discoveries—have been added to existing ones, but the instruments needed to study radio problems require more technical innovations than those for optical work. Optical researchers need new telescopes much like those in use, but radio astronomers require instruments with capabilities at short wavelengths and low energies that have become technically feasible only recently.

Optical Asronomy

Construction of new optical instruments has been under way for several years. Two telescopes with apertures of around 150 inches are being built by the United States, one by France, and one by a British-Australian group. A 234-inch telescope—the world's largest—should be completed by the Soviet Union in about a year.

Recent proposals include plans by the Carnegie Institution to establish an observatory in the Southern Hemisphere. Site development and construction of a 40-inch telescope at Los Campanas Mountain in north-central Chile have been started and the institution is presently looking for ways to finance a 200-inch telescope similar to the one at Mt. Palomar.

Another observatory in the Southern Hemisphere is being considered by astronomers from M.I.T., Harvard, and Yale. They eventually hope to construct a large telescope, but at present are proposing a $2-million site development and construction project for 36-inch and 90-inch instruments at an unspecified site in Chile. The project is not far enough along for definite commitments for funds to have been made.

A proposal from New York calls for financing to be done entirely within the state. At a meeting on 14 November, the New York Astronomical Corporation, an organization formed 2 years ago to look into state astronomical needs, recommended that a 150-inch telescope and a 48-inch support telescope be built at Mauna Kea on the island of Hawaii. New York astronomers hope that the state government, private industry, and philanthropic gifts will meet the $20-million capital investment and $2-million annual operation budget.

There are a number of research jobs waiting for the new instruments. Smaller telescopes—those less than about 75 inches—are useful for educational purposes and for some kinds of basic research. For example, their ability to measure motion and spectra of stars and gaseous nebulae within the galaxy contributes to stellar evolution studies. Studies of this kind have enabled theorists to successfully develop models for stars through all but the very early and late stages of their evolution. The smaller telescopes can also be used for some extragalactic work such as photometry of galaxies; and they are valuable for follow-up studies of discoveries made with new rocket and satellite instruments capable of observing at infrared, ultraviolet, and x-ray wavelengths.

Intermediate size telescopes—those from about 75 to 100 inches—can be used for the same tasks as small telescopes and, with favorable circumstances, can make many galactic observations usually made with large telescopes. However, there is no substitute for large instruments in studies of faint objects at very great distances.

One of the main jobs for the large telescopes and good intermediate instruments is to measure the size, shape, and distance of galaxies. These studies are leading to an understanding of galactic evolution, and some observations—especially those of the extremely energetic galactic cores—should reveal information about basic physics. These problems are intrinsically interesting but also have cosmological significance because information about the history of the universe can be derived from knowledge of the evolution of galaxies.

Another job for the large telescopes is the study of quasars. There are three problems associated with the red shifts of these objects that require much more study. First, there is the question of whether or not the red shifts of quasars, like those of galaxies, are the result of the expansion of the universe. Second, there seems to be a statistically significant clustering of the red shifts about a single value. An understanding of these two problems could result in a choice among several cosmological possibilities that are currently being considered. The third problem is that of multiple (as many as five) red shifts. Since not more than one red shift can be due to the motion of the entire quasar, the other must be due to some local phenomena, such as anomalous magnetic or gravitational fields or differential movement of matter within the quasar. When the cause of the multiple red shifts is understood, it is likely that the physics of quasars will be better known. The physical nature of quasars should also become clearer as the present effort to determine the similarities between quasars and galaxies is advanced.

Answers to these questions will require thousands of hours of observing time on the best facilities available, but almost all the important research in the United States on the problems is done on only three telescopes—the 200-inch Mt. Palomar telescope, the 120-inch Lick instrument, and the 84-inch telescope at Kitt Peak. And use of the latter instrument is only possible because of the high caliber auxiliary equipment, good seeing conditions, and skill of the observers.

Whitford Recommendations

The need for large optical telescopes was already apparent in 1964 and was one of the factors that prompted the National Academy of Sciences to appoint a committee under the chairmanship of Albert Whitford, director of the Lick Observatory, to evaluate needs of American astronomy. After surveying existing facilities, evaluating the potential of the space program for astronomy, and reviewing the significant research areas, they reported their findings in *Ground Based Astronomy: A Ten-Year Program*—a document also known as the Whitford report.

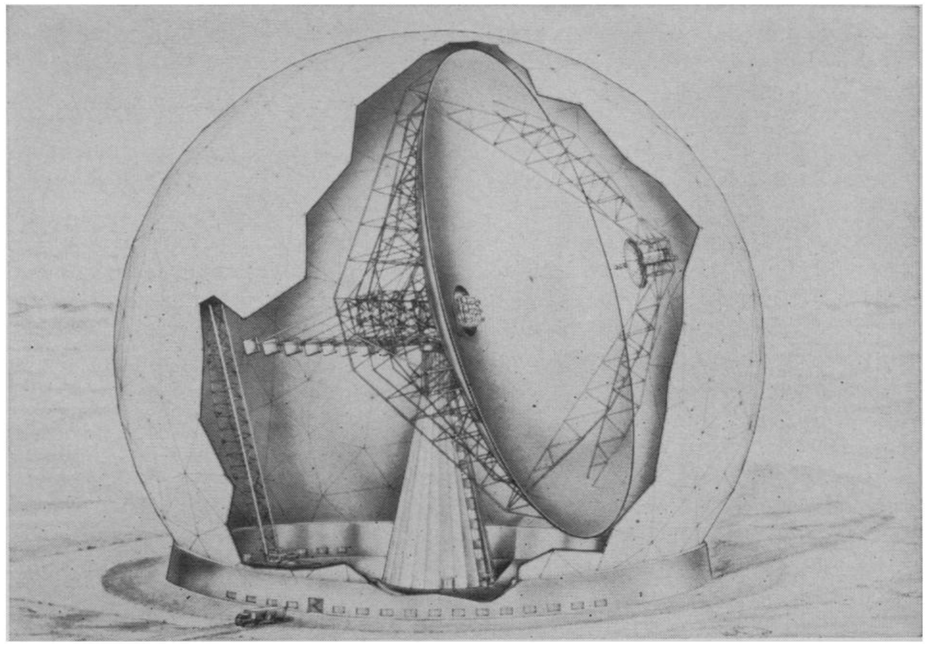
The major recommendations for construction of optical instruments were: (i) three telescopes in the 150- to 200-inch class, at least one of them in the Southern Hemisphere; (ii) four telescopes in the 60- to 84-inch class; and (iii) eight telescopes in the 36- to 48-inch class.

These recommendations have fared rather well. As the Whitford committee was working, the Associated Universities for Research in Astronomy (AURA) —the consortium of universities that runs Kitt Peak National Observatory—was planning a 158-inch telescope to be completed at Kitt Peak by 1972. Since then they have established the Inter-American Observatory at Cerro Tololo, Chile, where they plan to have another 158-inch instrument completed by 1973. Either the Carnegie or New York telescopes, if built, would complete the requirements for large instruments, and recommendations for the smaller instruments have been met several times over.

For major radio astronomy instruments, the Whitford committee recommended: (i) a very large, high-resolution array with 30 to 40 separate dishes; (ii) an eight-dish array for the Owens Valley Observatory in California; and (iii) two fully steerable 300-foot paraboloids.

One of the eight dishes for the Owens Valley array has been finished. Two fine-tracking paraboloids, which Whitford now calls "serendipity dishes," have also been built. These are the 120-foot Haystack antenna at Lincoln Laboratory (Massachusetts) and the 210-foot Goldstone antenna at the NASA Deep Space Institute (California). The Haystack dish is available for astronomical use about 25 percent of the time, but its instrumentation has been highly automated for tracking, and therefore many man-hours are required to use it for research. The Goldstone instrument is used for astronomy less than 5 percent of the time.

After 3 years, with only the one Owens Valley antenna and the "serendipity dishes" completed, the National Science Foundation appointed a panel headed by Robert Dicke of Princeton to consider proposals for radio facilities that had been submitted to the foundation. In June 1967, the panel recommended a series of proposals similar to but more specific than those of the Whitford Committee. The recommendation for the eight-dish array at Owens Valley remained the same; for the very large array the panel recommended a 36-inch dish array proposed by the National Radio Astronomy Observatory (NRAO); and in place of two 300-foot dishes they recommended a single 440-foot dish proposed by 13 universities known as Northeast Radio Observatory Corporation (NEROC).



Cutaway view of the proposed 440-foot radio telescope enclosed in a 560-foot radome. The radome, even if constructed primarily of fiber glass and epoxy as planned, would reduce the collecting efficiency of the dish to that of a 400-foot telescope; but since the instrument would not have to be strengthened to withstand the weather, greater steering accuracy and better precision of the paraboloid surface can be obtained. The design was developed by the Northeast Radio Observatory Corporation with support from the National Science Foundation. [Northeast Radio Observatory Corporation]

The Dicke panel had also recommended that engineering studies on the proposals continue. They met again last summer to consider these studies, which were the same except that NRAO cut their 36-dish array down to 27 dishes in an effort to make it more economical. They decided that their original recommendations were sound and should be made again—this time with a sense of urgency.

Radio Research

Even if no new problems had been found, a 5-year lag in major construction would generate a sense of urgency among radio astronomers, but in the past few years several important discoveries have introduced new research topics. The most spectacular of these was the detection of pulsars early in 1968. Pulsars are now believed to be neutron stars that result from supernovae explosions. Most of their energy comes from the rotation that produces their major pulsation period, and the radio signals are produced when particles that are spun off at relativistic speeds pass through the strong magnetic fields of the pulsars. The particles that escape from the gravitational field probably become cosmic rays; thus, for the first time since their discovery near the beginning of the century astronomers can directly study the origin of cosmic rays.

Although most people working on pulsars accept the model of the spinning neutron star, there are dozens of specific observations that are not adequately explained by the model. As details are worked out, it will be possible to learn more about not only neutron stars but also about the behavior of matter in magnetic and gravitational fields that are hundreds of times stronger than anything that can be produced on earth.

The 440-foot paraboloid would be an excellent instrument for the study of pulsars. Its large collecting area would make it possible to detect weak signals; the precision of the paraboloid surface would enable it to obtain the radio spectrum at wavelengths down to about 1½ centimeters; and it would be possible to integrate measurements of time-varying properties over several hours because the pulsars could be tracked.

The 440-foot paraboloid would also be useful for the recently developed technique of long base-line interferometry. Two separate radio receivers can obtain the same resolution as a single dish with a diameter equal to the distance between the two receivers. (A single dish, however, could detect very much weaker signals.) Using dishes separated by thousands of miles, astronomers have resolved objects to within 5×10^{-4} second of arc—about a thousand times better than the 200-inch Hale telescope. Quasars, which appear as point sources in optical telescopes, have been shown to have finite diameters, and there are indications that some of them have dense, energetic cores—an important observation in the effort to determine the similarities of quasars and galaxies.

Resolution in long base-line interferometry depends on a small ratio of wavelength to base line, so the 440-foot telescope's proposed sensitivity at centimeter wavelengths would result in favorable ratios. Its large collecting area would enable it to detect weaker signals, and its steerability would allow it to operate near the horizon.

A research area with less glamor than pulsars, but with as much potential for contributing to advances in astronomy, is the study of interstellar ions and molecules. In the past year radio astronomers have found neutral molecules of water, ammonia, and formaldehyde in regions where previous studies had revealed hydrogen and hydroxyl ions. The water and hydroxyl have strong emission lines that are believed to be the result of natural maser action, which implies that there is a strong source of infrared radiation to power the maser. It has been postulated that the source is a protostar in the vicinity of the gas clouds; therefore, studies of these areas should reveal information about the very early evolution of stars which is impossible to obtain with optical telescopes.

The Owens Valley array, in addition to being able to measure lines that are emitted in the centimeter range by two of the molecules—water and ammonia—would be a good instrument for spectroscopic analysis of the sources. Eight dishes give the array enough collecting area so that relatively weak signals can be detected, but the number is not so large that prohibitively large amounts of computer time are required to analyze the data.

Pulsars and the interstellar clouds provide astronomers with the opportunity to extend their ideas about stellar evolution into very early and very late stages, and most of the pertinent research must be done with radio telescopes. These instruments are also required for some of the most important cosmological problems currently being considered.

The most important event for cosmology in recent years was the detection of the microwave background radiation at a temperature of 3° Kelvin. Although the background was discovered with radio instruments, none of the three instruments being proposed now is particularly satisfactory for its study. However, a few astronomers have argued that the background is not the result of the "big bang" at the beginning of the history of the universe, as is generally believed, but is the combined effect of discrete radio sources that are too numerous and too weak to be detected with present radio telescopes. The very large array, if constructed, would have the capabilities necessary to prove or disprove this assertion.

A more basic use for the very large array is to work on the cosmological problem of the distribution of numbers and types of objects in the universe. For years radio astronomers have been working on a graph of the log of the number of sources below a certain radio brightness versus the brightness of the sources. If the universe is completely homogenous the line on the graph would have a slope of 1.5. At the present time it looks like the slope for faint sources is greater than 1.5, and for very faint sources it drops off very rapidly. This implies that the production of radio objects has not been uniform during the evolution of the universe. This result is not accepted with much confidence because no existing radio telescopes give reliable results for very distant objects; therefore, something with the capabilities of the very large array is needed to clear up the matter.

Recent studies show that quasars have time-varying emission at wavelengths from 20 centimeters down to atmospheric cutoff at about 1 centimeter. Time-varying phenomena provide important clues about the physical nature of astronomical objects, and so the very large array, with its proposed usefulness at 3 centimeters, would be a valuable instrument for quasar studies.

Why No Radio Telescopes?

In 1964 the Whitford committee estimated that their optical recommendations would cost \$68.2 million and their radio \$97.0 million. The NSF recently estimated that the recommendations of the Dicke panel for the three new instruments would cost \$115 million. The least expensive item, the Owens Valley array, would cost \$21 million—about twice the price of a 150-inch optical telescope.

Although the radio facilities have a larger price tag, it is difficult to explain why all but one of the major optical recommendations are under construction but none of the radio facilities has even been funded. Whitford suggested to *Science* that the large cost of individual items, rather than the overall cost, is an important factor in determining what gets funded. As examples he noted that 90-, 104-, and 88-inch telescopes are being built in Arizona, Texas, and Hawaii because these states made plans for observatories, arranged to obtain much of the funding locally, then got federal funds for millions, but not tens of millions, of dollars.

Whatever the reasons are for the lack of funding, they do not seem to apply to all countries. Next year Holland will complete a 12-dish array that will be the best instrument of its kind in the world. India has already completed an ingenious paraboloid surface trough that exploits its position near the equator in order to conduct studies that require special tracking.

Germany will have a 330-foot paraboloid completed next year, and England is planning a 450-foot paraboloid. This latter instrument will not be constructed, however, until the English finish their eight-dish array about 2 years from now. Another project about 2 years from completion is a 600-meter ring of disk receivers being constructed by the Soviet Union. If they meet their design specifications, the Soviets will be able to receive signals down to 8 millimeters.

In at least one case—that of Germany—the construction of a new instrument has resulted in a minor, reverse brain drain. Several American astronomers (most of them of German origin) are going to Bonn to work with the new instrument.

For a number of years radio astronomy has been an exciting research area, and a number of scientists, including several Nobel laureates, have come into it from other disciplines. It would be unfortunate if the momentum that has enabled the United States to make major contributions to the field is lost while other countries find money in their budgets for new radio instruments.

—ROBERT W. HOLCOMB