REPORT

of the

SECOND MEETING

OF THE AD HOC ADVISORY PANEL

FOR LARGE RADIO ASTRONOMY FACILITIES

Convened by the National Science Foundation in Washington, D.C., June 9-11, 1969, to consider proposals for design and construction of large radio telescopes.

Report dated August 15, 1969

NATIONAL SCIENCE FOUNDATION
Washington, D. C.

PANEL MEMBERSHIP

Dr. Robert H. Dicke, Princeton University (Chairman)
Dr. Bart J. Bok, University of Arizona
Dr. Stirling A. Colgate, New Mexico Institute of Mining and Technology
Dr. Rudolph Kompfner, Bell Telephone Laboratories, Inc.
Dr. William W. Morgan, Yerkes Observatory
Dr. Eugene N. Parker, University of Chicago
Dr. Gart Westerhout, University of Maryland
(Dr. Merle A. Tuve, Carnegie Institution of Washington, was a member of the original panel, but was unable to attend the second meeting.)

CHARGE TO PANEL

The Panel had its first meeting in July, 1967, almost two years ago. Since that time, it has not been possible to fund the construction of any instrument recommended by the Panel. However, progress had been made on several of the projects discussed in the recommendations, particularly on the continuation of design studies. The science of radio astronomy has made significant new discoveries and achieved new scientific importance. Some changes of an administrative nature have taken place, as for example the scheduled transfer of the Arecibo Observatory to the cognizance of the National Science Foundation, and the increased availability of the Haystack antenna for radio astronomy use.

The Panel was requested to reconsider its former recommendations in view of the progress which has been made, and to reaffirm or alter the recommendations and priorities in accordance with the present status of the proposed telescopes and of the science of radio astronomy.

RECOMMENDATIONS

Two years have passed without the implementation of any of the 1967 recommendations of this Panel for the construction of major new radio astronomical telescopes. A need that was then urgent has now become critical. While our country has stood still, Great Britain, the Netherlands, Germany and India have started new, large radio telescopes and several are essentially complete and ready for operation.

The ordering of the following recommendations is not on the basis of priority.

The Panel reaffirms its previous recommendation that the Arecibo telescope be improved and that the Owens Valley Array be constructed. It recommends, with equal urgency, the construction of the large radome-enclosed fully steerable dish and the Very Large Array. Certain technical obstacles to the construction of the latter two facilities have now been overcome. All of these facilities should be nationally available.

(a) The Panel is especially disappointed that the new surface of the 1,000-foot spherical dish in Arecibo, Puerto Rico, has not yet been constructed, and feels that the need for it is even more pressing now than it was earlier. It wishes to emphasize that the facility should be improved in its entirety and be made nationally available.

(b) The Panel sees no need to change its earlier recommendation regarding the Owens Valley Array. It again urges that the proposal by the

California Institute of Technology for an array of eight dishes be accepted in its entirety and funded as soon as possible, with an adequate operating budget, and that it be made nationally available.

(c) The Panel recommends with equal urgency that the final design and construction of a nationally available fully steerable 440-foot dish enclosed by a radome be started now. It further recommends that this final design upgrade as large a portion of the dish as is feasible for use at 1.2 cm wavelength, and that improved transparency of the radome at this wavelength should be sought. An attempt should also be made to improve the pointing accuracy to be compatible with the resolution implied above.

(d) The Panel recognizes the need for the Very Large Array, as proposed by the National Radio Astronomy Observatory. Because of the long time required to construct this array, it strongly urges that an immediate start be made on its construction, and that this construction proceed in stages over a period of several years. At the completion of each stage, that portion of the Array should be operational and available for observations. The Panel considers the prompt implementation of this recommendation important to the continued vitality of the National Radio Astronomy Observatory.

(e) The Panel is impressed with the progress made in the study of methods for building very large steerable dishes, particularly in the application of the principle of homologous structure deformation. The Panel recommends that such studies be continued, but oriented towards the engineering design of a very large antenna useable down to wavelengths of 3 to 6 millimeters.

(f) The Panel submits that the roots of the success of U.S. radio astronomy lie in the universities. It would therefore be a mistake not to support, at a high level, the universities from which have come the astronomers who make radio astronomy such an outstanding science. The Panel therefore strongly urges that parallel to the support of the major facilities, the support of radio astronomy research and facilities in the universities be substantially improved.

(g) It is important for the best progress of radio astronomy that unique facilities, such as those recommended in this report, be available to the maximum number of competent scientists and be programmed and equipped in such a way as to be responsive to the needs of the scientific community as a whole. For this reason, the Panel recommends that grants or contracts for Federal support of these facilities include not only a requirement that at least 50% of the observing time should be available to visitors, with priorities based on the relative merits of the proposals, but also require appropriate management arrangements to insure that policy is formed and operations are carried out with truly national representation and with the needs of visitors in mind. Ample electronic equipment and technical help should be provided so that the visitor, unfamiliar with the organization and perhaps less skilled in electronic matters, can effectively carry out his research. Sufficient operating funds to meet this need should be provided.

INTRODUCTION

The facilities for radio astronomy in the United States are essentially the same today as they were five years ago.

The dramatic and startling discoveries, made since the Panel met last, of pulsars, atomic and molecular lines, organic molecules, measurements of the galactic magnetic fields, and even a new test of general relativity, are to be contrasted with the tragic standstill in the funding of new facilities. In no other field of science has man's understanding -- even concept -- of his universe been so dramatically extended and altered. The view of the moon may now be both intimate and detailed, but the presently accepted proof of the neutron star state of matter is a fantastic confirmation of the exhilarating reach of theoretical science. Science proceeds by the mutual reinforcement between prediction and observation. It is therefore imperative that radio astronomy have both new and greatly improved facilities for observation.

The Panel emphasized in 1967 the pressing need for higher resolution and greater sensitivity, so that the study of smaller and fainter sources could be pursued. As intermediate steps the immediate upgrading of the Arecibo 1,000-foot telescope and the completion of the Owens Valley Array were recommended. The Panel stated that the NEROC proposal to build a 440-foot steerable parabolic reflector, giving high sensitivity, and the NRAO proposal to build the very large array (VLA), giving very high resolution, were both excellent proposals and clearly aimed at filling the progressing needs of radio astronomy. But the design studies, though well advanced, were not then complete, and needed further work on specific questions.

Now, after the passage of two years, the Panel finds that the NEROC and NRAO groups have both demonstrated the engineering feasibility of their respective instruments. The time has come to proceed with final design and construction of both instruments.

The Panel notes, too, that feeds for the Arecibo spherical reflector have been successfully designed, built, and operated with illumination patterns superior in some respects to those currently in use with parabolic reflectors. Continuing studies of spherical reflectors and feed systems for them are highly desirable.

Unfortunately, limitations of NSF funds have prevented implementation of any of the Panel recommendations of two years ago for new capital equipment. The Arecibo reflector surface has not been improved. Nevertheless, it remains the world's most sensitive radio telescope, though only at low frequencies.

No substantive moves toward the recommended completion of the Owens Valley Array have been made.

In the U. S. during the last two years, radio astronomy has advanced rapidly into new fields of fundamental knowledge, largely through the discovery and exploration of interstellar molecules, quasars, and pulsars (first discovered in England). The ingenuity and energy of our radio astronomers in pursuing the new fields of knowledge has been limited only by the number of hours in the day and, unfortunately, by massive cutbacks in financial support. The new states of matter represented by pulsars, interstellar molecular emission lines, etc., are of such fundamental interest to chemistry and physics, as well as astronomy, that their exploration will remain exciting and profitable through the foreseeable future, offering no prospect of abating.

Consider the recently discovered pulsars, now thought to be neutron stars. Present knowledge of the elementary particles (electrons, protons, neutrons, etc.) led to the realization some years ago that there might be such things as neutron stars in the universe. A neutron star would come into existence when the interior of an old massive star collapsed, packing a mass equivalent to that of the Sun into a small sphere of 10 km. diameter. The central density becomes 10^{14} times the density of water. At that enormous density the electrons are driven into the protons to form neutrons. The neutrons in the outer half of the neutron stars are believed to form a solid, with a strength many billion times greater than that of steel. The enormous pressure of the matter is confined by the equally enormous gravitational field, so strong that physical space may almost be pinched off, banishing the star from our view. More recent theoretical work suggests that the central part of a neutron star may be a fluid.

X-ray stars were at first thought to be neutron stars. It was later shown that they could not be. But then the pulsar was discovered. Extensive investigation has virtually ruled out all known possible explanations except that of the neutron star. It appears now that a pulsar is the remnant of a supernova explosion, rapidly spinning, and that it has a magnetic field of the order of 10^{12} gauss, one hundred thousand times stronger than the strongest fields that can be produced in a laboratory. This strongly magnetized neutron star, spinning as rapidly as 30 revolutions per second, should accelerate electrons and protons to nearly the speed of light, suggesting that pulsars may be an important source of cosmic rays. From the rate at which the 30-cycles-per-second frequency of the Crab Nebula pulsar is decreasing, an energy loss rate of 10^{39} ergs per second is inferred. This represents a million times the total energy output of the Sun.

The idea that matter and fields exist in the pulsar state is staggering to the imagination and is becoming a central subject in the study of the properties of matter. The sky is being searched systematically with the best radio telescopes to find more pulsars. At this time there are about 100 pulsars known, with a variety of different radio characteristics. The known number is increasing rapidly, and observation of the individual pulsars is intensively pursued.

It is in the midst of this rapid progress and excitement that the Panel once again takes up the question of the long term future of radio astronomy in the U. S. The need for increased sensitivity and increased resolution is more pressing than ever. In the last few years small interferometers have been used with great success to look closely at the new objects recently discovered in the sky. The results--few in number because of the large amount of time required to make the observations with the inadequate instrumentation--are sufficient to show the enormous variety and novelty of the radio galaxies, the quasars, the pulsars, the OH emission regions and other objects.

To the growing need for more resolution and sensitivity there has now been added the new dimension of short wavelengths. Several years ago it was generally believed that 5 to 10 cm were the shortest wavelengths for which detailed observations with large radio telescopes would be needed. It has now become evident that some of the most important new phenomena to be studied in the sky are the wealth of molecular lines and the unexpectedly high and variable emission from the quasars between 20 cm wavelength and the practical limit of observation (atmospheric cutoff) somewhere below 1 cm. Hence, we must consider new equipment to explore the Universe even at millimeter wavelengths.

It should be noted that there have been substantial advances in the development of radio receivers of very high sensitivity (low noise level) in the past few years. Many existing radio telescopes can be made much more effective at relatively modest cost by adding new receivers. Continued operation with antiquated electronics is a poor use of the capital investment of earlier years in the existing radio telescopes.

Finally, looking at the overall picture of radio astronomy, it is important to note that the other countries of the world which pursue radio astronomy are already well on their way to completing new and powerful instruments. Radio astronomers in the U. S. feel the disadvantages of our vintage radio instruments. The many years of construction and adjustment that go into modern radio instruments demand that we begin to move now while the present U. S. instruments are still productive.

To move this country into the next phase of development of radio astronomy with a minimum of cost and time, the Panel points out that in addition to the construction of new instruments, upgrading the existing ones is of equally high priority. These are steps of modest cost, designed to get the most out of what has been built in years past. Resurfacing the Arecibo telescope should be carried out immediately. Money should be invested promptly to take advantage of the enormous improvement in radio receivers, so that the existing radio telescopes can be used to their full efficiency.

But it is equally imperative to move ahead with the construction of the new instruments to meet the pressing needs for high sensitivity, high resolution, and short wavelengths demanded by the rapid progression of discoveries in radio astronomy. If the construction of new instruments, with their long lead-times (5-7 years) is not started now, the impetus of the most fascinating and important science of radio astronomy is bound to run out.

DISCUSSION OF THE RECOMMENDATIONS

(a) The Arecibo Antenna

We are particularly disappointed that funding for the new surface of the 1,000-foot spherical dish in Arecibo, Puerto Rico, has been deferred. For relatively little money, this already-existing very large telescope could be made useful for centimeter-wave radio astronomy. While its limited steerability is a handicap, this is more than compensated for by its enormous size. With an illuminated diameter as large as 700 feet, it promises to be for many years the largest single-dish radio telescope available in the world.

Earlier uncertainties connected with the line feed for the Arecibo dish have now been overcome and a design procedure has been developed that is capable of producing linearly polarized line feeds on a routine basis. Typically, only one month is required to produce a working line feed at a new wavelength. One benefit derived from the technique based on spherical surfaces is the controlled manner in which the line feed can be designed so as to generate any desired illumination pattern over the spherical dish.

It seems to be generally agreed that the Arecibo type antenna provides both the best and the least expensive approach to single-dish super-antennas, dishes over 600 feet in diameter. The experience to be gained from the improved Arecibo antenna is important for an orderly development of this exciting technique.

To be suitable for use by many outside visitors, the physical plant at Arecibo should be upgraded in addition to the dish, particularly with regard to visitor facilities; special attention must be paid to the newcomer-observer with a good program, who must learn to operate effectively with minimum delay after arrival. The electronic equipment and computing facilities should be of a high caliber and thoroughly dependable.

(b) The Owens Valley Array

The difference between the earlier (1966) proposal and the present state of affairs at the Owens Valley Observatory is impressive.

(1) The first dish (whose construction was already under way at the time of the Panel's first meeting) is finished. The structure, as expected, suffers more or less homologous deformations which can be compensated for by feed movement alone. Clearly, the pointing accuracy (1'.5 currently) still requires vast improvement.

(2) With the help of the NRAO, the group has investigated possibilities of increasing the separation of the array to reach higher resolution. It now appears that a resolution of 2" at 10 cm is feasible, and that resolutions below 1" at 3 cm are obtainable. Moreover, regions adjacent to Owens Valley have been investigated and possibilities exist for reaching a resolution of 1" x 2" or better at 10 cm and at declinations north of 20° in one day's observation. The Owens Valley facility offers the opportunity

of reaching resolutions of 0.1" in the Northern parts of the sky using portable antennas. Thus, some of the original restrictions on the useful size of the array appear to have been removed.

(3) In contrast to the first proposal, the California Institute of Technology group now puts special emphasis on line work. This is due both to the realization that the OVA is the optimum array for this work, and to the recent strong emphasis on radio line work as one of the most powerful means for studying the interstellar medium.

The Panel feels that the OVA should be made nationally available, that it should be operated and managed by California Institute of Technology, and that all the facilities and personnel necessary to accommodate many visitors with different backgrounds should be provided. It urges that funds be provided for the best available electronic equipment. In many observatories, lack of funds has prevented efficient operation of the facility. It is particularly important in an observatory that is to be made nationally available that great emphasis should be put on the reliability, versatility, ease of operation, and rapid changeover capabilities of the equipment. The Panel realizes that the expenses for forefront equipment might well be of the order of 20% of the cost of the total installation; it feels that such equipment will pay for itself by virtue of the increase in capability of the array.

The Panel suggests that the California Institute of Technology submit a plan outlining the management organization for a nationally available OVA and recommends that the Institute present a budget which would allow completion and operation of the facility at the highest level allowed by the current state of the art.

(c) The Fully Steerable Dish

The Panel remains convinced that the availability of a very large full-aperture, steerable antenna for the development of radio and radar astronomy in this country is of very high urgency. The opportunities such an instrument provides to the many University-based astronomers, because of its versatility and ease of operation, make such a telescope a unique tool for many radio and radar investigations of the solar system and of the Universe around us. With a large amount of effort, an array-type telescope could achieve many of the results obtainable with a dish. But the uniqueness of the dish stems from the way in which it can accommodate many experimenters simultaneously, and can follow up new discoveries rapidly and at minimal cost. Its versatility in being able to shift rapidly from one wavelength to another is one of the finest assets of a fully steerable antenna. Most new discoveries, both expected and unexpected, have been made with such dishes. Because of the rapid interchange of equipment, and the presence of many investigators at the same time, the chances for making new discoveries are tremendously enhanced. For many problems in the study of the planets, the interstellar medium, and the Universe beyond, long integration times requiring unlimited tracking capability are essential. For the study of time-varying phenomena, such as pulsars, steerability is desirable. For many problems the ability to measure complete polarization characteristics of both stable and time-varying objects is essential. Some parts of the sky (such as the center of the Galaxy) have unique properties and should be compared with other parts of the sky, again requiring full steerability.

The technique of using several independent dish-type telescopes in a very-long-baseline interferometer has been developed to a high degree. At present, the diameter of the earth is the only limitation to the longest baseline, and resolutions far below 0.01" have been achieved. Future work at this level of resolution is almost bound to lead to some of the most exciting new discoveries, for this resolution is two or three orders of magnitude better than had ever been previously achieved in astronomy, optical or radio. The combination of a very large fully steerable dish with independent existing small dishes or even smaller independent, portable dishes will eventually provide mapping capabilities to this accuracy. Large, single instrument collecting areas are essential, and the lack of a large fully steerable dish will ultimately prevent the breakthrough investigations foreseen for this technique.

The design study made by the Northeast Radio Observatory Corporation (NEROC) for a 440-foot dish in a radome, highly recommended for continuation by the Panel two years ago, has now reached the stage where it is clear that this instrument is not only feasible, but ready for final design and construction and possessing all the qualities mentioned above.

An *ad hoc* group of over 20 radio and radar astronomers, representing all major radio astronomical institutions and a wide variety of interests was convened by the Smithsonian Institution on November 30, 1968. Among other things, that group recommended that the present NEROC design be used as the basis for final design work for a large fully steerable telescope. It also restated the urgent need for such a telescope in the United States to assist in the solution of a wide range of important problems in astronomy and astrophysics.

The Panel wishes to endorse these conclusions strongly. The urgent need for such a telescope is proven beyond doubt. The instrument is ready to go into the construction phase. It is presently proposed that the instrument be funded either through the Smithsonian Institution, as in Senate Bill 705, or through the National Science Foundation. Regardless of the manner of funding it is evident that this instrument should be operated as a national facility.

In view of the increased realization (due to very recent discoveries) that many objects, including protostars and quasars, emit strongly at centimeter wavelengths, the Panel requests that in the final design of the large fully steerable dish particular attention be paid to the ability of reaching the minimum feasible wavelength consistent with the overall concept of the telescope. The Panel therefore recommends that as large a portion of the dish surface as possible be made efficient down to about 1.2 cm wavelength (just below the wavelength of the interstellar watervapor lines). The radome transparency and the pointing accuracy, obviously, should likewise be as close to optimum for this short wavelength as feasible. The Panel notes with approval that the telescope will probably be erected in the dry regions of the Southwestern United States.

The Panel feels strongly that in view of the tremendous need for such a dish, final design and construction should proceed with the utmost dispatch.

(d) <u>The Very Large Array</u>

In the 1967 report of this Committee it was noted that the present technique of laboriously synthesizing high resolution pictures with the aid of a few movable dishes required far too much time for the examination of many objects, that a sky survey at radio frequencies of the most interesting objects would require a large interferometer designed specifically to generate such high resolution pictures, and that the Very Large Array (VLA) concept of the National Radio Astronomy Observatory represents an excellent solution to this problem. It is important that an immediate start be made on the implementation of this proposal. This interferometer will be capable of generating radio wave pictures of 1" of arc resolution at a rate of 2 or 3 per day. It had been recommended by the Committee that study of this instrument be continued, to investigate and elminate technical uncertainties, and that during this design period a small interferometer be used at Green Bank to show that phase coherent techniques down to 1" arc are possible.

During the subsequent two-year period, a substantial number of interesting pictures down to 8" resolution have been produced and they give a clear indication of the wealth of information that should be obtainable with the VLA instrument.

Most of the technical uncertainties apparent at the time of our last meeting have been investigated and eliminated. We believe that the VLA has now reached a stage where it can be and should be implemented.

We do not place the VLA ahead of the OVA in urgency, but neither is there any implication that the VLA should be delayed until the OVA is completed. Both are desperately needed.

In recommending the implementation of the VLA by the National Radio Astronomy Observatory, we are mindful of the cost. Fortunately this type of instrument can be constructed and successfully used in stages. An incomplete array is still a very useful instrument, and the experience gained with the partial array can influence later construction.

(e) <u>High Accuracy Large Aperture Exposed Dishes</u>

The recent discovery of molecules in space, particularly H_2O and NH_3, as well as the observation of hydrogen, helium, and carbon recombination lines at wavelengths intermediate between 1 and 2 centimeters, emphasizes the need for a large steerable telescope capable of sensing radiation down to the shortest possible wavelength.

There exists a natural short wavelength cut off by oxygen vapor in our own atmosphere somewhat below 8 millimeters with a few additional isolated windows from 3 mm on down.

An antenna accurate for 8 mm use requires a surface accuracy with an rms error of ± 0.02 inches. Such high accuracy in a large antenna previously would have absolutely demanded a radome type of construction. However, radomes at these short wavelengths introduce their own problem associated with the attenuation by the more usual radome panel materials (fiberglas, epoxy). The NEROC antenna as presently proposed would be efficient down to 5 cm, and should be improved to be reasonably efficient down to 1.2 cm. As a consequence, there exists a strong motivation to design and build an antenna for still shorter wavelengths totally exposed to the sky. The requisite accuracy must of course, be maintained. Fortunately a study by NRAO points the way to achieving these conflicting requirements by (1) formulating a detailed computerized design procedure based upon homologous gravitational deflection and (2) providing a pointing reference platform servo-controlled by optical autocollimators.

The combination of both these features has been proposed by NRAO as the most economic solution to the requirement for a large, exposed and highly accurate antenna. The shortest accessible wavelength region below the water vapor cut-off requires an exposed design if the future low noise receivers are to be utilized to the limit of their inherent sensitivity. As a consequence, the Panel recommends that necessary support be given to NRAO to continue their studies of fully steerable dishes, several hundred feet in diameter, optimized for short wavelength use (down to 3 mm).

(f) Operating Costs and Support of Universities-

The Panel is much impressed with the need for the proper funding of operations and improvement of existing instruments. Of comparable importance to building new large facilities is the provision of adequate support for the effective utilization of existing instruments. Radio telescopes are operating at reduced efficiency because of inadequate financial support. The U. S. national facility, NRAO, has an operating budget of $4.8 M, one that will have to be increased particularly when the VLA gets underway. The requirements for operating funds for Cornell University (Arecibo), the University of California at Berkeley (Hat Creek), the California Institute of Technology (Owens Valley), the NEROC group of Eastern universities, and other universities alone add up to $7 M annually. This brings the present total annual operating budget for existing radio astronomical enterprises to $12 M, a figure that should be increased to $17 M annually within three or four years. It is realistic to count on an annual operating budget of $20 M, or greater, within the next decade.

The roots of the United States radio astronomical effort lie in the universities, and it is clear that we are restricting future development if we give insufficient support to the existing and developing radio astronomical centers at universities. For it is principally from these centers that come the scientific leaders at the professional and graduate student levels who produce the scientific work that makes our nation a proud one in the world's total radio astronomical effort.

The Panel wishes to draw attention to two further related aspects of the problems of operating budgets.

First, it has been repeatedly brought to our attention that existing radio observatories lack the funds for the construction of enough first-class receiving apparatus. Existing receiving equipment is frequently much poorer than the state of the art allows. With existing instrumentation the receiver introduces too much noise, giving the system a performance in signal-to-noise ratio comparable with that of a smaller antenna. But even when the noise figure of the receiver is good, the data reception rate could be doubled or even quadrupled by using double pole switching and observing two polarizations simultaneously. This situation must be remedied promptly -- and adequate operating budgets are a first step in the right direction.

Second, the budgets of radio astronomy groups at the universities should include funds for the construction of relatively small radio telescopes or arrays. In our search for excellence at the large facilities, we should not lose the interaction between the astronomer and graduate student which is so highly desirable. Projects at large national facilities must in general be planned in advance and in great detail, and there is no time to experiment. The past few years have demonstrated in optical astronomy that the development of the fine national observatories at Kitt Peak and Cerro Tololo has not lessened the need for moderate size optical telescopes in the range of apertures 24 to 90 inches, operated at or very close to university astronomy departments. A similar trend should be encouraged in developing university radio astronomy programs.

ADDITIONAL CONSIDERATIONS

The Haystack Antenna

The Panel also reviewed a proposal for funding the operating budget of the Haystack Antenna in Massachusetts to be operated under the auspices of NEROC. This costly large precision reflector (aperture 120 feet, operable to a resolution of 1½ minutes of arc at a wavelength of 1.2 cm) housed within a protective radome, can be made available for a greater amount of time for radio and radar astronomy by the Lincoln Laboratories of MIT. The Panel recommends that this enterprise be supported at a level consistent with that provided to other universities involved in teaching and research in radio astronomy and related fields, for it is a major operating facility that can do much to broaden the base of radio astronomy in the United States. Its principal attraction lies in its immediate availability.

Aeronomy

The Committee on Institutional Cooperation (CIC), a consortium of Midwest universities, has proposed that a 100-meter fully steerable dish together with two 66-meter tiltable dishes be constructed for research on the ionosphere at wavelengths in excess of 25 cm. This instrument would be useful for some radio astronomy,research, although it is not designed for this purpose and would not be able to reach the shorter wavelengths that now are of special interest in radio astronomy. Accordingly, the installation is in no way in competition with the antennas under consideration by this Panel, and it must be justified by its importance to aeronomy. If it were constructed, some research in restricted areas of radio astronomy could be accomplished with the facility.

The Southern Hemisphere

In the years to come, there will undoubtedly be increasing effort in the construction of precision radio telescopes of moderate aperture -- 100 to 200 feet -- for the millimeter and centimeter ranges of wavelength. At a very early stage, attention should be given to a southern hemisphere site. The existing radio telescopes in Australia and in Argentina are well suited to research in the decimeter and meter range, but high-quality dishes of reasonable aperture are sorely lacking for research at shorter wavelengths. The southern hemisphere is rich in celestial objects of great interest -- the Carina Nebula, the Vela supernova remnants, the Magellanic Clouds, to name a few -- and radio astronomy badly needs a Southern Observatory with radio telescopes operating at the shorter wavelengths.