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RESEARCH OBJECTIVES FOR LARGE STEERABLE PARABOLOID RADIO REFLECTORS

A Preliminary Report Prepared By
A Panel of Associated Universities, Inc.

April 22, 1955

The Report that follows was prepared by Bart J. Bok, Chairman of the AUI Panel established for the purpose of preparing a scientific justification for a variety of large steerable paraboloid radio reflectors with apertures of 150 feet, 300 feet and 500 feet. The present preliminary version has been written for the dual purpose of circulating it for comments among the members of the AUI Panel and others interested in the research objectives of large steerable paraboloids and to acquaint the National Science Foundation with some of the current trends of thought in this area.

The need for the present Report became evident at the meeting of the AUI Steering Committee for a National Radio Astronomy Facility held in New York on March 26, 1955. The members of the AUI Panel are: B.J. Bok (Harvard), chairman, A.J. Deutsch (Mt. Wilson and Palomar), Leo Goldberg (Michigan), J.P. Hagen (Naval Research Laboratory), J.D. Kraus (Ohio State), W.E. Gordon (Cornell) and M.A. Tuve (Dept. of Terr. Magn.,Carnegie Inst. of Wash.). The following astronomers and physicists contributed also to the discussion that is summarized briefly in the present Report: AUI: L.V. Berkner; Mt. Wilson and Palomar: J.L. Greenstein and J.G. Bolton; Dept. of Terr. Magn. Carnegie Inst. of Wash: H.E. Tatel, K.L. Franklin and H.L. Helfer; Michigan: L.H. Aller; Naval Research Laboratory: Various Staff Members;* Harvard: G.S. Hawkins, T.A. Matthews, T.K. Menon, E.M. Purcell, R.N. Thomas, J.W. Warwick, F.L. Whipple, Harold Zirin; Harvard and Bureau of Standard C.R.P.L.: R.S. Lawrence; Wesleyan University (Conn): D. S. Heeschen; Princeton: G. Field. *Haddock, Lilley, McClain.

I. SCOPE OF THE REPORT

At the New York meeting on March 26, the AUI Steering Committee decided to urge the immediate construction of a reflector of approximately 150-feet aperture, which simultaneously careful feasibility studies were to be made of designs for reflectors with apertures in the range of 300 feet, 500 feet and greater. Unanimous agreement was expressed by all present with regard to the importance of a 150-foot reflector for research in radio astronomy, and it was felt desirable to prepare a listing of some of the more important specific objectives in this area. It was furthermore considered highly desirable that careful attention be given now to the problem of preparing in addition a listing of objectives for paraboloids of greater aperture

As a guide, the members of the AUI Panel and others had before them a rough table of resolving power as a function of frequency for paraboloids of various apertures. It was noted by Kraus that the listed beam widths are "a trifle optimistic", since they apply to uniformly illuminated circular apertures. Because in practice it is necessary to taper the radiation toward the edge of the dish, the actual beamwidths are probably 10% to 20% greater than those given. We reproduce this table here in its original form:

Aperture \ Resolving Power	Frequencies in Mega Cycles per sec. 20Mc	100 Mc	500Mc	1420Mc	3000Mc
150 feet	20°	4°	48'	16'	8'
300	10°	2°	24'	8'	4'
500	6°	1°.2	14'	5'	2.3'
1000	3°	0°.6	7'	2.5'	1.2'

The concentration of our attention for the present on single steerable paraboloids of various large apertures, should not be taken to imply that the AUI Panel is not aware of the potentialities of other types of equipment Several members - notably Berkner, Kraus and Tuve - indicate that in their opinion a search and survey instrument should from the start be incorporated in the plan. The consensus of opinion seems to be that an instrument of the design suggested by Kraus shows great promise for the carrying out of a search for faint discrete sources over the entire sky and for some related survey studies. Several correspondents note furthermore that it would be premature to settle now on a design for a single large paraboloid mounted in standard alt-azimuth fashion and provided with a computer for the transformation to equatorial coordinates and vice versa. These matters are beyond the scope of the present limited Report, which is concerned only with the problem of outlining research objectives for paraboloids of large aperture. The same objectives should, however, apply equally to many instruments of modified design.

Members of the AUI Panel and other correspondents stress almost without fail the need for <u>precision</u> equipment of large aperture. The importance of research with large aperture equipment at 21cm and even at 10cm is stressed, which leads directly to a requirement of high precision of the reflecting surface in all positions of the instruments. Much emphasis is placed on provisions for precise positioning. Several correspondents point out the need for versability of the equipment and for special facilities for the interchange of auxiliary equipment with a minimum of lost observing time. It is generally felt that electronic and mechanic developments should go hand-in-hand and receive comparable emphasis.

Berkner and Purcell ask that from the start much attention be given to techniques of information gathering, such as multiple feeds and multiple channel systems. Purcell went so far as to predict that in the final design of the large instrument one might decide to sacrifice the high degree of steerability generally envisaged for research of the type that concerns us here and design our instrument with limited steerability, and with electronic equipment capable of gathering records in fairly short intervals. Feeds that would permit the following of an object for a short time may be constructed, electrical phasing techniques may be employed and limited mechanical following can be built into very stable and mechanically simple equipment.

Berkner mentions that the design problems of very large dishes are probably not unsurmountable and that precision of surface may be maintained to very short wavelengths. He urges that the advantages of large gain should not be overlooked. Large gain may in the end prove to be fully as important as narrow beamwidth and for many experiments the large gain may prove decisive.

2. 21-CENTIMETER RESEARCH

There is a general consensus of opinion that a large paraboloid will lead to remarkable advances in the study and interpretation of the 21cm line of neutral hydrogen. A 150-foot antenna with a precision surface that permits use of the full aperture should open up entire new areas for research in the structure of our own and other galaxies. It is too early to imagine now what new frontiers will be opening up if a 500 foot antenna can be used effectively for 21cm research.

Much attention must be given in the 21cm field to continued development of electronic equipment. One may predict with confidence that with increasing aperture there will be demands for increasingly higher frequency resolution, lower noise figure, increased zero stability and greater speed of recording. Studies of the continuum in the centimeter and decimeter range are surely going to increase in importance as 21cm research advances and will place further demands upon the designer of electronic equipment.

Our correspondents have provided the chairman of the AUI Panel with a wide array of projects for 21cm research. The potential usefulness of a 150-foot reflector and larger equipment is described concisely by Hagen and his associates at the Naval Research Lab. in the following words:

"The added resolution provided by an antenna of larger aperture is needed to delineate the spiral structure of the gas clouds in the galaxy and thereby to contribute toward a better understanding of galactic dynamics. It is in this field that the 21cm hydrogen work has already made giant strides with the limited equipment presently available.

"The structure and content of the galactic nucleus presents a special problem that is of extreme importance but which can only be touched upon with presently available antennas. A 150 foot antenna would increase by a factor of three todays best resolution. With the larger antenna it is possible that one could answer the questions as to whether the source seen in this direction is actually the nucleus.

"The work at NRL has revealed that in some instances the small scale structure of the gas can be seen. This occurs when one is fortunate in finding a cloud or two aligned with a radio discrete source. With the larger dish the beam width will be small enough that individual clouds may be resolved and seen in emission. Gas and dust associations may then be investigated in detail. In addition, with the larger antenna the absorption measurements will be accentuated and profiles in more detail obtained.

"Whether there is HI in the nearer extragalactic nebulae can only be answered with the aid of an antenna much larger than those available today. This measurement, if made, could yield Doppler shifts with much greater accuracy than can be had through measurements of visible spectrum lines. Studies of clusters of nebulae and a possible intergalactic medium would also be undertaken."

Tuve and his associates draw attention to the fact that for 21cm research the resolving power of the 150-foot reflector (16') suffices to make available for analysis a long list of objects beyond reach of existing equipment, the principal ones of which are HI shells around emission nebulae, HI clouds associated with absorbing clouds responsible for multiple interstellar absorption lines, HI clouds near OB associations and those associated with dust clouds of modest dimensions, galactic and globular star clusters. With still larger equipment objects with diameter of the order of 5' and smaller can be studied adequately and in addition to those already mentioned globular, planetary nebulae, novae, shell stars and stars with very extended atmospheres should become accessible to observation and analysis by 21cm techniques.

Greenstein writes as follows about some potentialities for research at 21cm with a 500 foot antenna:

"The resolution at 21cm is sufficient to detect individual small clouds of gas at the distance of the galactic center, and therefore, at least in certain favorable regions, to permit a rather detailed mapping of the distribution of hydrogen gas in the entire galaxy, in the inward hemisphere as far as the galactic center, and for substantially all of the outward hemisphere. The same would be true of small clouds at a considerable height above the galactic plane. Similarly small dark objects, and the effects of 21cm absorption can be studied very favorably, as the size goes up to the 500-foot range. Both the emission and the absorption spectra of discrete sources are much favored by the large aperture."

The opportunities for 21cm research in our own galaxy with instruments of increased aperture are great, but one might almost be tempted to minimize them when comparing them to the potentialities for research into the structure and dynamics of our neighbor galaxies and the remote fainter galaxies. The Australian studies of the Magellanic Clouds have demonstrated already what may be done with relatively small apertures in the study of our nearest neighbors the Magallanic Clouds. At the distance of the Andromeda Nebula (Messier 31) the spiral features have widths of the order of 5', which means that with a 500 footer we shall be able to obtain adequate resolutions for measures of velocity over the entire accessible area of this spiral nebula. With high precision of radial velocity measurements attainable in 21cm research, we should obtain much needed basic information for dynamical studies not only for M 31, but also for M 33, NGC 6822 and other members of the Local Group. Aller points out that from these studies we should be able to deduce the mass distribution in several of these objects.

Turning to the more distant galaxies, a variety of problems is suggested. Bolton recommends that a special attempt be made to measure the Doppler shift attributed to the expansion of the universe, to check whether or not it holds over the entire range from optical to radio wave lengths. Zirin suggests that one should look for intergalactic absorption effects from HI seen in front ofdistant discrete sources (Cyg A and the like). Again Doppler shifts and cut-offs should be noted as bearing on the expanison of the universe. Accoring to some of Zirin's preliminary calculations measureable HI absorption may be produced even if very cold HI ($T \sim 1^{o}K$) were to exist in intergalactic space with a concentration as low as $N_4 \sim 10^{-4}$ cm^{-3}.

Matthews points out that studies of the integrated radiation from members of the Local Group are feasible with antennas of 150-foot apertur e and greater. Seven ofthe 25 members of the Local Group, the M81 Group and the M 101 Group fill the beam of a 150-foot antenna and practically all would fill the beamwidth of a 500 foot antenna. Several correspondents draw attention to the possibilities for study of intergalactic neutral hydrogen, especially bf HI associated with clusters of galaxies.

Returning in conclusion to the galactic system, we mention a suggestion from Field. He notes that some of the NRL absorption features at 21cm are very sharp in the case of Cassiopeia source. Apparently the small angular dimensions of some sources permit us to look in absorption at clouds of very low velocity dispersion and this encourages one to look for Zeeman effect from interstellar or circumsteller magnetic fields. For maximum effectiveness one requires angular resolution comparable to the angular dimensions of the source - that is of the order of a few minutes of arc - and large aperture of the antenna is required for tests of Zeeman effect.

3. GALACTIC AND EXTRA-GALACTIC STUDIES OF THE RADIO CONTINUUM.

Almost without fail, the members of the AUI Panel and other correspondents list important researches in the continuum for large paraboloid reflectors in the range of aperture 150 to 500 feet.

At meter wavelengths, the large paraboloids are recognized to have important tasks ahead of them in the measurement of precise positions, radio magnitudes and radio colors for one hundred-or-so of the brightest sources. They will be the instruments used for the precise study of sources discovered by the search instrument. Possibilities of useful interferometric studies would be offered if provisions were made for a second paraboloid of modest proportions mounted on a railroad track and to be used in conjunction with the paraboloid reflector of aperture 150 feet and greater.

There is some disagreement with regard to the question of large interferometers and "Mills Crosses" interforming large paraboloids at long wavelengths. Deutsch expresses the opinion that "at meter wavelengths in existing high-resolution instruments the effective aperture is already large enough to allow measurement of a signal above instrumental noise in all directions". He recognizes the limitations (lack of steerability, work at one single frequency, ambiguities caused by side lobes, lack of precision in setting) of existing equipment, but feels that these may be overcome. "Interferometers can be steered and the spacing varied for frequency range; or, at no very great cost, they are Mills Crosses can be multiplied at different latitudes for coverage of the sky, and at different dimensions for coverage of the spectrum. The essential point is that at meter wavelengths a paraboloid is seriously overpowered for its resolving power."

At the present state of knowledge of radio radiations in the meter range, the importance of precise positions for discrete sources must be clearly stressed. Because of the extreme faintness of the few optical objects that have been identified with certainty with strong radio emitters in the meter range, there is little hope of similar optical identification of faint radio emitters unless, their positions are accurately known.

The importance of "special classification" from studies of the distribution of radio brightenss with wavelength for fairly large numbers of discrete sources is emphasised by several correspondents. The large paraboloid - possibly fitted with multiple feeds - offers great possibilities for advance in this area and the versability of the instrument becomes here of prime importance. Kraus points out that the very large paraboloids may prove to be most effective in overcoming ionespheric difficulties at long wavelengths - in the range of several meters and longer.

Franklin and Helfer point to the advantages of large paraboloids in the search for line emissions and absorption features at wavelengths other than 21cm. Searches for the radiation from deuterium (at $\nu \approx$ 327 Mc/sec) and OH (at $\nu =$ 1668 Mc/sec) have already been made in this country and abroad (notably in the USSR) and the discovery of additional line features is almost sure to come. Here the high gain combined with high angular resolving power of the large paraboloids will prove important since the search can be concentrated on special objects and on selected regions of the sky most likely to yield results.

There is complete agreement among our correspondents with regard to the great importance of paraboloids in the 150 to 500 feet range for research in the continuum at wavelengths from 50cm downward. The importance of attempting to reach to 10cm waves with even the larger apertures is stressed by many correspondents. The researches of Haddock and others at the Naval Research Laboratory have demonstrated the important of searches for and studies of emission nebulae that produce measurable radio radiation of thermal origin in the short wavelength range. Increased gain and resolution will not only lead to numerous discoveries of thermal radiation in the decimeter range, but - as Hagan and Aller stress - intensive detailed studies of radio brightness distribution become possible for the larger HII Regions. Comparative studies of radio and optical isophotes promise to yield very useful results regarding physical conditions in the emitting gas and scattering effects by the interstellar medium between the HII Region and the sun. Studies of the spectral intensity distribution in the continuum should certainly be extended to the shortest possible wavelengths and the single large antenna should be helpful in attempts at classification and the sorting of emission mechanisms. It might be possible to distinguish several "spectral classes" among the radio objects too faint for identification with optically observable objects. Tuve lists the problems of radio spectral classification as among the most critical ones of radio astronomy.

4. SOLAR RESEARCH

The preliminary justification for a paraboloid antenna with an aperture of 150 feet or more rests upon the research potential of the instrument for galactic and extra-galactic studies. The instrument has, however, great possibilities for solar work and for studies of the solar system, and these are treated in the present section and the section to follow.

For advantageous use in solar research, the large paraboloid antenna should preferably be a steerable one and should provide access to the sun for the greater part of the day. The high angular resolution of the large paraboloid and its high gain can be used to advantage in two varieties of solar problems.

Bolton and the Harvard solar physicists stress the importance of an extension of J. P. Wild's researches on dynamical spectra to short wavelengths and to weak disturbances. The infinitely broad band feature of the paraboloid combined with its large collecting surface renders the instrument particularly useful for research in this field. In the words of Bolton:

> "The problem is the study of solar outbursts in the cm.-metre range -- i.e. an extension of Wild's work to the high frequencies (the same aerial would also do for the low frequencies). Some of these disturbances move so fast that extremely high time-resolution equipment is needed and this in turn requires large collecting surfaces to offset the loss of any integration. The larger the aerial is, of course, the smaller the disturbance that it can measure and the faster statistical information is accumulated. At the moment Wild is lucky to collect even one or two outbursts per year with his relatively small aerials."

Goldberg and Hagen emphasize the importance of the relatively high angular resolution in all directions which is obtained with a large paraboloid. This feature should assist greatly in disentangling several simultaneous radio and optical disturbances during times of great solar activity -- such as we may expect at the time of the forthcoming sunspot maximum. Goldberg attaches great importance to the high gain of large antennas especially in the measurement of intensities at high frequencies of radio bursts associated with optical flares. Another problem noted by Goldberg is that of the measurement of radio radiation from individual prominences in the 10-centimeter range -- which requires high gain and great angular resolution -- and which should throw light on the temperature problem.

5. THE SOLAR SYSTEM -- RADAR TECHNIQUES

While there are certain problems relating to the reception of radio radiation from the planets (Jupiter, for example; the work of Burke and Franklin), the primary use of large antennas in studies of the solar system lies in the use that can be made of the instrument in the transmission and reception of directed radar pulses. This topic has been made the subject of a special study by Berkner, which we shall summarize here briefly. After derivation of the equations for the strength of the received return signal, Berkner notes:

"The equations show the very large effect of dish size in acquiring the necessary range as compared to the adjustments of any other parameter. If the dish size is doubled, the required power is cut to 1/16th. If the integration time is doubled, the power cut is only $1/\sqrt{2}$. The integration time must be increased 256 times to permit cutting the power by the same amount as doubling the dish size. While all other methods of increasing range and speed in radio astronomy must certainly be used, there is no substitute for dish size as an essential element of the job. Moreover, particularly in active radio astronomy, the motions of the sun and the planets with respect to the earth are such as to restrict sharply the interval over which integration can be made effective. Finally no other method of obtaining a sufficiently sharp beam is available if the beam is to be pointed quickly and effectively in any direction, or to track a target having any complex motion."

After consideration of various factors that mitigate against the receipt of a return signal reflected by the sun and by gas clouds in the sun's atmosphere, Berkner concludes that

"for a successful and well-rounded program of active radio astronomy on the sun, the minimum perimeters are a 550 to 600 parabola and a pulser providing up to 1 millisecond pulses of not less than 5×10^5 watts peak power. As shown in the later calculations on the planets such a large dish should be provided with a pulser to provide 1 megawatt pulse with available variation of duration between 10^{-4} seconds and 10^{-1} seconds on a duty cycle of about one in a thousand. This would provide for an excellent program of research into solar phenomena.

"Therefore, one is led to the following tentative conclusions with respect to active radio astronomy on the sun.

" "With the 600-foot dish, a modulator capable of producing pulses of the order of 10^{-3} seconds with an amplitude of 1 megawatt on a duty cycle of 1 in a 1000, it is very probable that a thorough examination of the solar phenomena could be made by radio astronomical methods. This would include:

1) Measurement of wave-absorption versus wave-function over a wide range of wave-frequencies to reach to the different levels of the solar surface.

2) Movement, density, and other characteristics of moving masses associated with solar eruptions.

3) Movement, and to some extent composition, of particle streams from the sun.

4) Examination of structure and composition of the sun's corona.

5) Measurement of magnetic fields including weak magnetic fields in the specific regions of the sun's surface.

6) Possible measurement of magnetic fields associated with moving particle streams from the sun.

7) Examination of details in localized regions on the sun using very high frequencies associated with very narrow beam widths."

In the case of the planets much useful work can be done with large antennas. For Venus we again quote from Berkner's essay:

"Therefore, we conclude that using a 524-foot dish and modulator capable of pulse durations between 10^{-3} and 10^{-4} seconds and peak power of 10^{6} watts, we can:

1. Obtain echoes from Venus at all times.

2. During intervals of Venus' near approach to the earth, measure the density of the electrification of its ionosphere and consequently of certain characteristics of the atmosphere such as depth, scale height, and perhaps an estimate of composition and temperature.

3. Determine the rate of axial rotation of Venus by observing decay of the ionosphere on the dark side with the changing phase of the planet.

4. Measure the exact location of its nearest surface at near approach to $\pm$ 18 kilometers and at farthest departure to $\pm$ 50 kilometers.

5. Observe dust on particle clouds or perturbations in such clouds in the vicinity of the planet.

6. Measure the magnetic field of Venus through differences in the Zeeman penetration of the ionosphere."

These detailed listings of problems for the sun and Venus should suffice to show the power of the approach and the importance of large steerable paraboloids for this kind of research. The extension of these considerations to the cases of Mars and Jupiter is almost self-evident and no detailed accounts will be reproduced in our Report. There are many other studies noted by Berkner for which comparable techniques may be employed -- for example in the investigation of reflections form interplanetary ionized clouds, the ring current suggested by the Chapman-Ferraro theory of geomagnetic storms, detailed structure of the ionosphere, meteoric phenomena and aurora. Radar pulse techniques have obvious applicability to the moon -- where high angular resolution will prove especially advantageous. Hawkins points to the possible use of pulse techniques in the search for extra satellites in earth-moon system.

Hagen and Whipple draw attention to the importance of direct high-resolution studies of the surface of the moon and possibly of the planets. The following quotation from Hagen's report summarizes the situation briefly:

"Lunar Studies

At a wavelength near 10 cm, and perhaps at a substantially longer wavelength near 50 cm, measurements of surface temperature and brightness distribution along the equator of the moon can be correlated with existing data for millimeter and infra-red wavelengths to clarify knowledge of the electrical and thermal properties of the soil of the moon. For sufficiently accurate measurements, the low temperature of the lunar surface requires the use of sufficient antenna gain to treat the moon as an extended source.

Planetary Measurements

Given sufficient surface precision, a large antenna may make it possible to detect and measure thermal radiation from several of the planets, particularly Venus, Mars and Jupiter, at a short centimeter or millimeter wavelength. In the case of Venus, these observations would have the advantage of measuring radiation from the surface level deep in the atmosphere of clouds, as opposed to infra-red measurements which may not penetrate deeply within the cloud layer."

6. CONCLUSION

The foregoing brief summary seems to show conclusively that the time is ripe for the prompt construction and placing into operation of a 150-foot steerable reflector. There seems similarly every reason to proceed now with the planning for another larger steerable instrument even though all concerned realize that many of the problems raised in Section 1 must be investigated before decisions as to exact type, degree of steerability and the like, can be made. The need for an additional large search instrument is evident and its detailed design and construction should be undertaken promptly.

In concluding the present Report, your Chairman can probably do no better than to reproduce two summarizing statements, the first a quotation from Greenstein's letter — the paragraph in which he describes his attitude toward the need for a 150-foot paraboloid --, the second, the introductory paragraphs from Hagen's reply to our inquiry.

"If one fixes one's attention on the 150-foot size, may I say that I believe there are a few problems to be expected in the construction of such a device. It is a conservative and safe step forward over those already built, or known to be capable of construction, such as the 80- or 90-foot size. It would be the largest single precision paraboloid in this country, and presumably could become an all-purpose instrument for use by all cooperating groups. Because of its precision construction, ability to track objects, versatility of uses, it is probably the most satisfactory single device for use by cooperating groups. Unlike special-purpose instruments, such as interferometers, it is very likely that receiving equipment and feeds can be changed rapidly, so that a large number of various programs can be carried out over a period of time. Therefore as a nation-wide facility, it has very great promise and will undoubtedly lead to important results. In the 21 cm problems its resolution, space penetration, power, etc. are simply those mentioned in my previous discussion of the larger paraboloid, scaled down proportionately to the size. I believe that this would give excellent detailed information on the study of the gas clouds in our own galaxy, and possibly also in the Andromeda nebula. For studies of spectral energy distribution of known sources, it will provide freedom from interference of neighboring sources, and possibly even give the brightness distribution across the large sources. The hot gases of ordinary emission nebulae can be studied, and at high frequencies it is undoubtedly true that the total amount of material in such nebulae as the Orion nebula or other emission objects can be better obtained from this device than from any optical techniques I know, because of the freedom from interstellar absorption which the radio frequency measures provide. In addition for the emission nebulae in which there happen to be any large-scale motions, it is possible that a clear proof of the presence or absence of non-thermal noise-generating mechanisms may be obtained. As is known in the very high-velocity colliding gas clouds this non-thermal generation is a steep function of frequency, and while the mechanism is unknown, studies of ordinary nebulae may permit us to get a clearer grasp on it. A general sky survey for extended sources, distribution of sources in space, statistics, the frequency of different spectra, all can be carried out with a 150-foot size, and should give us a clear picture of the radio universe in which we live."

"The notion that the sky is full of stars and that we live in a universe of stars and clusters of stars is retreating. Radio astronomy looks into space and sees not the stars but the new material that exists between and around the stars. The early work revealed the presence of the material, but now we must refine our tools and search for the nature and the disposition of this tenuous material out of which half the material in the universe is composed. Its true nature can be defined only when we have available instruments of great flux-gathering ability and great resolving power. In this we follow in the footsteps of the optical astronomers. Such a large instrument must be a parabolic reflector to give resolution in all planes and to be available for use at all wavelengths.

"The availability of such an instrument will allow us to solve many of the vexing problems, raised by the limitations of present equipment, facing us today, but more important will bring to light many things that are today unknown and in that sense unpredictable. As in nearly every other science the experiences in radio astronomy has been that the acquisition of new and superior equipment, designed to round out or fill in the picture obtained with present equipment, has led to new discoveries."

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