Minutes of Meeting
of the
AUI Advisory Committee on Radio Astronomy
October 16-17, 1956

November 12, 1956

1. The AUI Advisory Committee on Radio Astronomy met in the AUI office, New York City, on October 16-17, the following persons attending all or a part of the meetings:

B.J. Bok, Chairman	Harvard College Observatory
L.V. Berkner	Associated Universities, Inc.
J.G. Bolton	California Institute of Technology
L.R. Burchill	Associated Universities, Inc.
A.J. Deutsch	Mount Wilson & Palomar Observatories
C.F. Dunbar	Associated Universities, Inc.
F.K. Edmondson	National Science Foundation
R.M. Emberson	Associated Universities, Inc.
W.E. Gordon	Cornell University
F.T. Haddock	University of Michigan
W.F. Harwood	National Science Foundation
D.S. Heeschen	Associated Universities, Inc.
E.F. McClain	Naval Research Laboratory
A.B. Meinel	National Astronomical Observatory
C.B. Ruttenberg	National Science Foundation
H.W. Wells	Carnegie Institution of Washington

On Tuesday evening, October 16, the Committee met for dinner at the Century Club as the guests of Dr. Berkner, and discussions followed, primarily on the matter of the selection of the Director for the Observatory.

2. The first item on the agenda was a discussion of the 140-foot radio telescope program. The subject was introduced by a letter from Mr. Grote Reber, written in Tasmania on October 7, wherein he questioned the wisdom of proceeding with the 140-foot telescope, noting that its size is such that either an equatorial or altazimuth mount is feasible and that much time and effort will be wasted fighting this issue. He proposed that we abandon the 140-foot telescope; that we get started promptly at Green Bank with a 60-foot telescope similar to the Harvard instrument; that we look ahead to a large telescope, one significantly larger and more precise than any telescope now planned or under construction. Specifically, Mr. Reber proposed a 600-foot telescope which he felt confident could be designed according to the following specifications:

Diameter	600 feet
Mounting	Altiazimuth

Accuracy inside half radius	±1/4 inch) (in all
Accuracy overall	±1/2 inch) (positions
Focal length	250 feet
Minimum angle below horizon	2 degrees
Weight	15-16,000 tons
Cost per ton	5-800 dollars
Cost, less drive and foundations	10,000,000 dollars

3. It was noted that the NSF presentations to the Bureau of the Budget and the Congress were centered on a 140-foot telescope and that the available appropriation for the establishment of the Observatory had been made with the understanding that a 140-foot telescope would be built. Accordingly, the Committee considered the specifications for the 140-foot telescope recommended by a group of engineering consultants on September 25-27:

Wind Condition	Zero Wind	16 mph Wind
Paraboloid surface	±1/4"	±1/4"
Absolute pointing accuracy	±30"	±40"
Relative pointing accuracy*	±10"	±20"
Tracking accuracy over 15 min time	±10"	±20"
Tracking accuracy over 1 hr or more	±20"	±40"

*Relative pointing accuracy is defined as the accuracy with which the telescope can be moved from one point to another point, assuming the subtended angle between points is under 30 deg and that both points are 30 deg or more above the horizon.

4. In the discussion of performance requirements (Item 1.2 of the agenda) Mr. Haddock submitted a memorandum prepared by Prof. Aller and himself, which is attached hereto as Appendix A-1.2, urging that all features of the telescope be made good for observations at 3 cm. wavelengths. Others joined in supporting this general objective, but it was noted by Mr. Bolton that the design experience at Cal Tech indicated a reduction from ±1/4 inch to ±1/8 inch would double the cost of the reflector. Drs. Bok and Heeschen pointed out that all reflectors to date had been better than the design specifications, e.g. the Harvard 60-foot reflector was aimed at a 1/2-inch precision and actually is good to about 1/8-inch, and Prof. Bijlaard has computed that the 140-foot reflector proposed by the D. S. Kennedy Company would have gravity deformations of the order of 1/10-inch. The consensus was that the 140-foot reflector should be aimed at ± 1/8-inch precision, under a no-wind condition and at zenith distances of 60° or less. Also, under these ideal conditions, the feed should be held at the focus with a precision of 1/16-inch

rather than 1/8 inch. It was further agreed that limited sky-coverage should be specified for an equatorial telescope, although it was hoped that greater coverage could be achieved; the minimum acceptable coverage would be the portion of the sky bound as follows:

> From the pole along a great circle to the east point of the horizon; along the horizon through the south point to the west point, from the west point along a great circle to the pole; one or two degrees loss along the horizon would not be serious.

It was also agreed that the 140-foot telescope need not be capable of motions in galactic coordinates with the same precision as in equatorial coordinates; furthermore, the special additional units for giving smooth tracking in galactic coordinates need not be included in the basic telescope drive.

5. Subsequent to the September 25-27 meeting of engineering consultants, a series of homogeneous cost estimates were being prepared on the available 140-foot telescope designs. Because of the limit set by the available appropriation, the relative costs of the various telescope designs must be considered in reaching a decision on which telescope to build and the homogeneous cost estimates will facilitate this review. Meanwhile, plans had been made to proceed with a "definitive" 140-foot equatorial design, the work to be done by Prof. Ashton with the advice of a special ad hoc committee. Mr. Bolton agreed to make the Cal Tech 90-foot telescope design information available and volunteered to serve on the ad hoc committee. The Department of Terrestrial Magnetism telescope design was mentioned and it was noted that pursuant of a conversation with Drs. Tuve and Tatel last summer, Dr. Tatel was being asked to serve on the ad hoc committee.

6. Concerning the alignment and testing of the 140-foot telescope, Prof. Haddock reported of his photographic alignment procedure, using a 4-inch Ross camera with 32-inch focal length. (A setting accuracy of two microns on the plate would correspond to 1/2" of arc). Dr. Heeschen described tests that had been made with the Harvard 60-foot telescope; an important aspect was a discontinuity in tracking as the telescope crossed the meridian. The consensus was that the 140-foot telescope design should provide for adjustment of both axes (e.g. polar axis should be adjustable in both azimuth and elevation and the declination axis should be adjustable to a plane perpendicular to the polar axis). Because optical or photographic methods will be employed for the final alignment of the telescope, proper mounting positions for these instruments should be provided on the frame of the telescope.

7. Methods for checking the reflector surface were briefly reviewed. Primary methods, e.g. those capable of self-calibration, appear to be slow and costly, although a precision of 1/8-inch seems to be technically feasible. The Army Map Service has proposed an optical survey procedure, estimated to require about 700 man-

hours and to cost $8,000 per survey; the stereo camera method suggested by Dr. Feld was not recommended because existing equipment could barely meet the desired precision. A microwave procedure, proposed by a group at Rensselaer Polytechnic Institute, is being critically reviewed. With reference to Section 4 above, if a 1/8-inch tolerance is desired for the reflector, the check procedure should be capable of a precision of 1/16-inch or less. Such precision would appear to be nearing the limits of presently available techniques. Prof. Haddock suggested that the situation might warrant a re-examination of procedures such as an 8-mm radar located at the focus, or a microwave knife-edge test, as was investigated by Irving Gerks several years ago. In this regard, it should be noted that the minimum distance at which a source should be placed to get essentially a plane wave at the paraboloid is given by $2d^2/\lambda$, where the diameter of the paraboloid, d, and the wavelength, λ, must be in the same unit as the minimum distance. In view of these difficulties, it might be warranted to expend more to have the panels of the reflector sufficiently rigid to retain their respective shapes and to rely on a check of the position of the corners of the panels with the use of a precision theodolite mounted at or near the vertex of the paraboloid.

8. At a later point in the meeting, questions were raised concerning studies toward a larger (600-foot) telescope. It was explained that the matter had not been forgotten but it did not appear to be feasible to push these studies at this time.

9. Item 2 of the agenda was concerned with 28- and 60-foot telescopes for the Observatory. It was noted that the uncertainty in the cost of the 140-foot telescope would not permit the obligation of funds from the FY 1957 budget for either a 28- or 60-foot telescope. It was agreed, however, that the need for a 28-foot telescope had not changed. But the consensus was that when money for a 60-foot telescope becomes available it should not be committed until the Director has had an opportunity to review the situation and to decide whether a 60-foot telescope or some other observing equipment is more urgently needed.

10. Item 3, concerning the Green Bank site, noted the report on foundation borings and the West Virginia Zoning Act. The status of applications to the FCC for protection of the Green Bank site and, more generally, for protection of frequency bands of interest to radio astronomy were discussed at considerable length. Mr. Porter had supplied copies of the AUI Comments as well as those of other groups or agencies. Some opposition was expressed by users of the 38 mc communication band. Aeronautical Radio, Inc. a company serving all commercial air lines, objected on a broader basis and included the 1420 mc band in its objections. Mr. Wells reported that the CCIR (International Radio Consulting Committee) at the Warsaw meeting adopted a resolution favoring the reservation of certain frequencies for radio astronomy. Because of Dr. Hagen's role as a representative of both URSI and the NSF Radio Astronomy Panel, a telephone conference was held with him. It was agreed

that Messrs. Gordon, Hagen, Porter, and Wells would work together, both for the preparation of an AUI "rebuttal" and also in coordinating other presentations. The AUI "rebuttal" is attached hereto as Appendix A-3.3.

11. A decision had been made by the NSF to acquire the site through the services of the Corps of Engineers, the title of the Observatory to rest with the Federal Government. A map was displayed that showed the area for direct purchase; the area for protection through covenant or by purchase; and the area for protection by covenant, if feasible. Having in mind the tightness of the FY 1957 bidget, the Committee discussed the advisability of reducing the area to be acquired and considered bringing the northern boundary down to the "MM" coordinate on the map. But after further discussion the consensus was that the area shown on the display map should be acquired, including all the tract north of the central area where the first construction will be located, i.e. to approximately a northern boundary of "VV" on the map.

12. Equipment had been purchased for recording wind speed samples at Green Bank. Arrangements had been made with the Naval Research Laboratory for the loan of mobile equipment to permit the commencement of radio astronomy observations at Green Bank. (Subsequently, on October 25, 1956, this equipment was installed and observations started).

13. The discussion of Item 4, budgets for the Radio Astronomy Observatory, were based on $4 million for FY 1957 and about $1.13 M for FY 1958. Drafts prepared by AUI indicated how these funds might be obligated, the entire discussion being under a cloud of uncertainty because the 140-foot telescope item is uncertain and represents more than half of the total. The AUI drafts contained only major equipment and construction items; operating funds for the two years would be in addition to the above amounts. It was noted that the 140-foot control building should be larger, perhaps to cost $35 - 40,000.

14. The discussion of Item 5 noted the completion of the Planning Document and passed on to the reading by Mr. Harwood, of the NSF Board's resolution on contracting with AUI for the operation of the Observatory. A copy of the resolution is attached hereto as Appendix A-5.2. Contract negotiations between the NSF and AUI have been proceeding.

15. Dr. Berkner led the discussion of Item 6, plans for future activities. He reported that a special committee, under the chairmanship of Dr. Menzel (the other members being, I.S. Bowen, W.W. Morgan, C.D. Shane, Otto Struve, J.B. Wiesner) was preparing a slate of nominees for the directorship. It was hoped that the Director might be designated soon, even though it might not be possible for him to assume full-time duties for a semester or

longer. During this interval, the Director would serve as the chief scientific advisor for the construction program; would recruit the permanent staff; and would plan and initiate the research program. Meanwhile, the development of the site and the construction of the 140-foot telescope would proceed under the guidance of an AUI staff (presently consisting of R. M. Emberson, J. W. Findlay, and D. S. Heeschen). Construction of the 140-foot telescope will require 18 months to two years from the date of awarding the contract; if no delays are experienced, the permanent observatory staff and visitors can start research at Green Bank at an earlier date. Adequate electrical power, buildings, etc. should be ready in a year.

Copies to:
All people at the meeting

Encls:

Appendix A-1.2 - Memo by Aller & Haddock - 10/15/56

Appendix A-3.3 - AUI Reply Comments - 10/22/56

Appendix A-5.2 - NSF Board Resolution

Appendix A-1.2
Minutes of 10/16-17 Meeting

SOME CRITICAL OBSERVATIONS OF GASEOUS NEBULAE THAT CAN BE SECURED ONLY IN THE CM-WAVELENGTH REGION

L. H. Aller and F. T. Haddock
October 15, 1956

There are a number of observations, critical to the interpretation of both planetary nebulae and of the H II regions of diffuse nebulae that can be made only in the radio frequency region. The value of combining optical-region and radio-region observations of diffuse nebulae such as Messier 8 and M 20, the Trifid nebula was demonstrated by Burgess.[1] The effect of space absorption can be evaluated by comparing radio and optical measurements and improved estimates of the electron density and temperature can be obtained.

We propose that with a 140-foot diameter antenna of sufficient precision a series of radio-frequency observations of planetaries and small H II regions can be made so that when these data are combined with accurate optical region observations, information not obtainable from the latter alone can be found.

The objective of the radio-frequency observations is the following: To determine the energy distribution (and its absolute value) from about 1 cm to about 50 cm or a meter so as to distinguish between the thermal and any non-thermal component of the r.f. radiation. The intensity of the thermal component of the radiation will enable us to estimate the amount of space absorption and hence

correct the densities and temperatures derived from the observations of the optical region of the spectrum. Currently, attempts have been made to estimate space absorption in planetaries from one of two methods:[2] (a) assume the Balmer decrement to be given by the theory for recombination in an optically thick nebular or (b) compare the intensities of the Paschen and Balmer emission lines that have the same upper level. Method (a) postulates that no collisional excitation is present whereas method (b) supposes that the substates of the n-th level are populated strictly in proportion to their statistical weights in spite of the cascading processes through which they are filled. Measurements of the pure thermal radiation would enable us to obtain a correction for the space absorption effect free of these objections and then obtain not only improved estimates of the electron density but also an improved interpretation of the Balmer decrement. Is collisional excitation really important? In what ways do the theoretical calculations of the intensities in the hydrogen spectrum need improvement?

Possible non-thermal radiation poses even more interesting problems. The shapes[3] of a number of planetaries strongly suggest the presence of magnetic fields and therefore we might not be surprised if some synchrotron radiation were present. Polarization of the continuous radiation, so easily observable in the Crab nebula, would be difficult to detect in the planetaries where most of the radiation comes from forbidden lines which are collisionally

excited and the small amount of pure continuum is hard to measure quantitatively. Hence, non-thermal radiation, if present, might more easily be detectable in the r.f. region.

Therefore it becomes necessary to observe the energy distribution in the continuum over a large range in wavelength - from the shortest possible (1 cm would be ideal but we may have to compromise to 2 or 3 cm) to about 50 cm. At the shortest wavelengths only pure thermal radiation is likely to be detected; at the longest wavelengths the thermal contribution falls off and non-thermal radiation (if present) would dominate. Experience with Orion, M 8, etc.,[4] shows that in the region 10-20 cm appreciable component of non-thermal radiation would have falsified the energy distributions. To isolate the thermal from the non-thermal components, it would be necessary to study the range from 2 or 3 cm to 10 cm. We cannot overemphasize the importance of the separation of thermal and non-thermal sources for the physical interpretation of gaseous nebulae.

A narrow pencil beam pattern is necessary to separate the planetaries (many of which fall near the Milky Way and its central bulge) from nearby H II regions and other radio sources. The question of a narrow beam pattern becomes even more important in a more accurate study of diffuse nebulae such as M 17 where a patchy interstellar absorption strongly affects the optical isophotic contours and integrated optical brightness. We would like to be

able to deduce the true shape of the emission region from observations at a very short wavelength in order to estimate the exact amount of space absorption. Boggess' discussion was hampered by the lack of angular resolution of the r.f. data. If observations of M 17 be made at 2 or 3 cm with a 140-foot dish the true shape could be deduced with sufficient accuracy for a meaningful combination of optical and r.f. data to be made.

Reference 5 tabulates on page 149 fifteen planetary nebulae which have been sufficiently studied at optical wavelengths so that the thermal radio emission can be estimated. When this is done it is found that all 15 could be detected with existing receivers coupled to a 140-foot paraboloidal reflector at all wavelengths from 3 to 20 centimeters. Several other planetaries can be added to this list.

It is our contention that the 140-foot antenna should be built to a precision sufficient for use at a wavelength of 3 centimeters in order to study planetary and diffuse nebulae which we know can be of immediate value to presently existing programs in astrophysics. Of course, further arguments can be based on the recent detection of Mars and Venus at 3 centimeters.

Only a small fraction of the sky has been observed at centimeter wavelengths, and it is therefore virgin territory for fresh exploration. Contrary to the general impression there is actually an

increase in the radio intensity from non-thermal sources, both solar and galactic, as higher frequencies are approached if one calculates the intensity on a percentage bandwidth basis and this seems a logical way to consider it. Furthermore, it is only at centimeter wavelengths that we have any appreciable understanding of the mechanism of radio generation and it appears to date, that only this mechanism is dominate. Whereas at meter wavelengths at least two processes are of comparable importance, and therefore of more intrinsic complexity of interpretation, especially when the poorer angular resolution, and poorer transmission through the inosophere, is considered.

A principal reason for the existence of a National Radio Observatory is the great expense of building large antennas, and if they do not build a large antenna for centimeter wavelengths, who will? Should the U. S. follow in the footsteps of other countries in asking only for a 10 to 20 centimeter wavelength limit? Other countries are building larger steerable paraboloids which are planned for 21 cm wavelength. Should not the U. S. continue its lead in the centimeter wavelength region by asking for 3-centimeter performance under the best observing conditions?

REFERENCES

[1]Albert Boggess III, Thesis University of Michigan 1954.

[2]See e.g., Minkowski, R. and Aller, L. H., ApJ. 124, 110, 1956.

[3]Cf. Minkowski's observations of e.g., NGC 650-651, MH α-362, CD-29°13998, NGC 6537, described in Chap. 7, Reference 5.

[4]F. T. Haddock, "Hydrogen Emission Nebulae as Radio Sources," IAU Manchester Symposium on Radio Astronomy, 1955.

[5]L. H. Aller, "Gaseous Nebulae", John Wiley, New York (1956).

Appendix A-5.2

excerpt from letter to Dr. L.V. Berkner from Alan T. Waterman dated September 4, 1956.....

At its meeting in Woods Hole, Massachusetts on August 24, the National Science Board passed the following resolution:

> The Board unanimously AUTHORIZED the Director to proceed with negotiation of a five-year contract with the Associated Universities, Inc., for the establishment and operation of a Radio Astronomy Observatory subject to a clear understanding with the AUI that the Foundation will give serious consideration to the possibility of establishing at the end of that time a common management for the Radio Astronomy Observatory and for the Optical Astronomy Observatory; it is to be further understood that the selection of the Director and of the AUI Advisory Committee for the Observatory will be made in consultation with the Director of the National Science Foundation.

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington 25, D. C.

In the Matter of	)	
	)	
Amendment of Part 2 of the Commission's Rules and Regulations to give interference protection to frequencies utilized for Radio Astronomy	)	Docket No. 11745

REPLY COMMENTS OF ASSOCIATED UNIVERSITIES, INC.

Associated Universities, Inc. (AUI) submits herewith its reply to certain comments received by the Federal Communications Commission in response to its Notice of Proposed Rule Making adopted June 20, 1956 (released June 22, 1956).

1. Aeronautical Radio Inc. (ARINC) points out in its comments that the proposal to reserve the frequencies set forth in the appendix to the Notice of Proposed Rule Making is in conflict with existing international agreements to which the United States is a party, and states - "It is our belief that this action cannot be taken unilaterally by the United States".

2. In reply, AUI desires to invite the Commission's attention to the recommendation for protection of frequencies used for radio astronomical measurements made by the CCIR at the recently held Warsaw meeting which are as follows:

"RECOMMENDATION: PROTECTION OF FREQUENCIES USED FOR RADIO ASTRONOMICAL MEASUREMENTS

The CCIR, considering:

(a) that protection from interference in radio astronomical measurements is required;

(b) that for the observation of known spectral lines, certain bands at specific frequencies are of particular importance;

(c) that account should be taken of the doppler shifts of lines resulting from the motion of the sources which are, in general, receding from the observer;

(d) that for other types of radio astronomical observation, a certain number of frequency bands are in use, the exact position of which in the spectrum are not of critical importance;

(e) that a considerable degree of protection can be achieved by appropriate frequency assignments on a national rather than an international basis;

(f) that, nevertheless, it may be impractical to afford such protection in or near populous or industrial regions;

recommend:

(1) that radio astronomers should be encouraged to choose sites as free as possible from interference,

(2) that Administrations should afford all practical protection from interference to radio astronomical measurements in general, but give particular attention to the protection of observations of line emissions known to, or thought to, occur in the following bands:

Line	Lined Frequency (mc/s)	Band To Be Protected (mc/s)
Deuterium	327.4	322 to 329
Hydrogen	1420.4	1400 to 1427
O H	1667	1645 to 1675

(3) that Administrations, in seeking to afford protection to particular radio astronomical observations, should attempt to limit harmonic radiations following in the bands indicated above.

NOTE: Administrations might consider the dual advantage to radio astronomy of reserving, or otherwise protecting, the second and third sub-harmonic (1/2 and 1/3) of the line frequency band which could then be used for other radio astronomical purposes."

3. The above-noted recommendations are indicative of the fact that radio astronomy is recognized by other nations of the world as a necessary and important scientific endeavor, and that protection of the line frequencies

and their subharmonics are required in order to permit the science of radio astronomy to extend the range of knowledge of the fundamental laws of science and furnish new data useful in the conduct of engineering, commerce, and the national defense.

4. Where specific conflicts exist between present users of radio frequency spectrum space and the reservation of spectrum space proposed for radio astronomy, such conflicts should be made the subject of specific proposed rule making so that an opportunity may be presented by both sides to demonstrate which use is more important in the public interest.

Respectfully submitted,

ASSOCIATED UNIVERSITIES, INC.
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BY /s/ William A. Porter
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Its Attorney

October 22, 1956