DRAFT
GK:amk
12/10/57

M.P.E. STAFF PAPER

THE SCIENTIFIC NEED FOR VERY HIGH MECHANICAL PRECISION IN THE PROPOSED 140 FOOT "DISH-TYPE" RADIO TELESCOPE FOR THE NATIONAL RADIO ASTRONOMY OBSERVATORY

G. Keller

The usefulness of a "dish-type" radio telescope for research purposes may be said to depend on three factors (1) the diameter of the dish, (2) the precision with which the surface of the dish is shaped and the accuracy of the mounting which is used to support it and (3) the quality of the auxiliary equipment which is used to analyse the cosmic radio waves which the dish collects.

The larger the dish diameter of a dish-type telescope, the fainter the radio source which can be studied with it. This factor in turn affects the number, variety and distances of the celestial objects which can be studied with it. In order that the proposed instrument may be at least several times more effective than any existing telescope of its type, the diameter of 140 feet has been chosen. Although an even larger diameter would be scientifically desirable, the 140 foot size seems to be indicated by economic factors and the present state of the radio telescope maker's art.

A large dish is essential if one is to study faint sources, but the accuracy with which the nature of the object can be studied also depends directly upon the accuracy with which the dish itself is made. A crudely made radio telescope has faults very similar to those of a crudely made optical telescope of the conventional type. A poor optical telescope forms blurred images. Pictures of objects which occupy adjacent positions in the sky are run together. Pictures of extended objects such as the moon and planets are blurred and details cannot be seen. In a similar fashion a poorly made radio telescope cannot distinguish between a single radio source and two radio sources which are close to one another in the sky. Details of the structure of extended radio sources such as planets and nebulae are lost, and most of the potential usefulness of the instrument is lost. For this reason an accurately constructed dish and mounting are essential.

A word about the length of the radio waves which can be received by a radio telescope is essential here. For the purposes of illustration it is again useful to cite to a similar case in optical astronomy. Some colors of visible light (blue and violet) have shorter wave lengths than others (red and orange). The colors and wave lengths of the light emitted by celestial bodies depends on how hot the bodies are, what they are made of and how fast they move. By measuring the colors or wave lengths of the light from a celestial body which is under study, a great deal of vital information about its physical nature can be obtained. The same principal applies to the radio radiation from a celestial radio source. Although the invisible radio radiation has no color, it does vary in strength from wave length to wave length. The greater the range of wave lengths which can be received with a particular radio telescope, the greater the amount of useful information we can obtain concerning its physical structure. The proposed 140 dish-type telescope will be capable of receiving radio wave lengths down to about an inch, thus making it by far the largest radio telescope in existence capable of working in this range. It will be capable of resolving important details in the structure of the moon's surface (in radio radiation), of observing fine details of the structure of the Milky Way and of probing properties of interstellar and interplanetary matter which are quite unobservable with any existing or planned equipment.

It seems to be the opinion of virtually all leading radio astronomers both in this country and abroad that the proposed telescope is needed for very important research problems and that it should be built.

The foregoing remarks are made on the assumption that adequate auxiliary equipment is available for analysing the radio signals which are received by the telescope. Equipment of this sort is now being purchased by AUI for the National Radio Astronomy Observatory. From time to time advances in the techniques of electronics will make it desirable to obtain better auxiliary equipment. But there is no question that present plans call for the aquisition of equipment which will make full use of the unusual potentialities of the proposed telescope.

Detailed descriptions of some of the important problems of present day radio astronomy (which can be investigated with the proposed telescope) are given in the Appendices. Dr. David S. Heeschen is an astronomer at the NRAO. Drs. Lawrence Aller and Fred T. Haddock, Jr. are astronomers at the University of Michigan.

Appendix I

Some Centimeter Wave Programs for the 140-ft. Telescope

D. S. Heeschen, December 2, 1957

1. Positions of sources: One of the prime needs of radio astronomy today is the accurate determination of source positions, for identification and other purposes. The 140-ft. telescope, used at 4 cm wavelength, will be an extremely powerful instrument for determining source positions. Its beamwidth at 4 cm wavelength is about 4 minutes of arc. For a point source, the relative position can be obtained from an observation with an accuracy of about - beamwidth/signal to noise ratio. A 4 cm receiver recently developed has a noise of 0.01°K. Thus a 1°K signal has a signal to noise ratio of 100, and an error in position measurement, due to signal fluctuations, of 2.4 seconds of arc. Additional errors arise from the position indicator dials and from telescope deflections in front of the indicator take-off points. The indicators on the 140-ft. will be good to 3 seconds of arc. Calibration of other errors will be made by observing planets, with the above mentioned receiver. It appears possible to measure positions of point sources having atenna temperatures greater than 1°K to an accuracy of about 10 seconds of arc. Judging from Haddock's work at 3 cm, and from the intensities of sources at longer wavelengths, there should be more than 100 such sources available to the 140-ft. Positions of 100 sources to an accuracy of 10 seconds would be of tremendous value. The best that has been done so far is one minute of arc accuracy, and this for only a very few sources.

2. Planetary nebulae and H II regions: See attached report by Aller and Haddock.
3. Galactic background radiation: In order to separate the thermal and non-thermal components of the background emission it is necessary to observe it in the 3 cm-10 cm wavelength range. Once the thermal component is isolated, with sufficient resolution, its degree of concentration to the plane, its origin, etc. can be studied more effectively. The need for a cm wave study of the background emission was emphasized at the Stockholm Conference on Coordination of Galactic Research, especially by Oort. The nature and origin of the non-thermal component too, can be effectively studied only after the thermal component has been determined. The 140-ft. is an ideal instrument for such studies.
4. Planets: Thermal emission at cm wavelengths has now been detected from Venus, Mars, Jupiter, and Saturn. All the observations lie at the limit of detectability. The 140-ft. will be by far the best instrument for further studies of the cm wave emission from planets.
5. Spectra of sources: In order to study the origin of radiation from sources it is necessary to know the spectrum, preferably to very short wavelengths. In particular, the spectrum to 3 cm is desirable in order to separate thermal from non-thermal sources.
6. Polarization of source radiation: The polarization of the radiation from a source is an important parameter in studies of the origin of the radiation and the physical conditions in the source.

There has to date been only one successful observation of polarization of a source other than the sun (Mayers 3 cm observations on the Crab nebula), and even this observation is marginal. Because of the smearing effect of Faraday rotation and because of the need for high resolution and minimum instrumental effects, polarization measurements can best be undertaken with a large paraboloid working at the shortest possible wavelengths. This is a very promising field which has hardly been touched as yet, because of the lack of a suitable telescope. The 140-ft. may be able to contribute a great deal to polarization measurements.

7. Solar: The desirability of observing plages and other active regions on the sun, at cm wavelengths with high resolution, has been pointed out by a number of people, particularly Goldberg. The 140-ft., possibly with special techniques to increase resolution, should be very useful in this respect.

8. Radar: I hesitate to bring this up because I have mixed feelings about using the 140-ft. with radar. There is no doubt however that the 140-ft., operating at 3 cm, will be able to bounce radar signals off of the moon and several planets. Such experiments could be used to: determine solar parallax; study the nature of the reflecting surface of the planets involved, and possibly their atmospheres; test for presence of interplanetary materials.

9. Other spectral lines: This is speculative, of course, but there are various spectral lines in the cm wavelength region which might possibly be detected. The 140-ft. telescope is probably the only telescope currently being planned that has any possibility of detecting them.

Appendix II

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 freguency 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 Boggess.[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 <u>increase</u> 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).