Projects proposed radio astronomy.

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38, MASSACHUSETTS

April 13, 1954

Dr. Lloyd V. Berkner
Associated Universities, Inc.
350 Fifth Avenue
New York 1, New York

Dear Lloyd:

I am enclosing herewith an advance copy, which represents the result of several conferences that have particularly involved Jay Stratton and Jerry Wiesner of M.I.T., and Bart Bok, Fred Whipple, Cecilia Gaposchkin and myself for Harvard Observatory.

You realize of course that this is a very preliminary document and that participation will require formal approval by the appropriate university authorities. But you said you would like to have the information at the earliest possible moment.

I hope that this is the beginning of a new and important era in radio astronomy.

Cordially yours,

Donald H. Menzel
Director

cc: J. Wiesner
J. Stratton
McGeorge Bundy
Edward Reynolds

DHM/m

For reference I append a set of names from which you may want to choose the committee.

Wiesner hopes that the Steering Committee will be small, but I leave it up to you. There has been some question as to whether we should try to bring the West Coast or even the Middle West into the picture. However, here is the list with a few additions:

Jerry Wiesner
J. Stratton
J. Hagen
R. McMath
S. Goudsmit
W. Gordon
A. H. Shapley
A. E. Whitford
J. J. Nassau
H. Ewen
L. Tabor
A. Waynick
M. Tuve
J. Van Vleck
E. Purcell
N. Ramsey
R. Dicke
Ch. Townes

Menzel Chairman
Emberson,
Seeger

L. DuBridge
J. Greenstein
O. Struve

Brumms

It has been suggested that Waterman, Seeger and/or Piori might be invited.

Radio Astronomy Cooperative Research
Tentative Committee

SURVEY OF THE POTENTIALITIES OF COOPERATIVE RESEARCH

IN RADIO ASTRONOMY

Preamble. From relatively humble beginnings made in the 1930's, a new and important field of science has developed at accelerated pace during the last decade. This field, usually referred to as "Radio Astronomy", has two unique features, each seldom found, but even more rarely occurring in combination. First, the field employs an entirely new technique. Second, its scope ranges over an exceptionally broad area of science. It encompasses most of astronomy, from measurement of positions to modern astrophysics, from stellar distribution to cosmic evolution. It provides a probe for the geophysics of the upper and lower atmospheres. It crosses the frontiers of ultraspeed aerodynamics and astroballistics. It promises deeper insight into the problems of electronics in general and of radio communication in particular. In physics, it embraces such areas as the electromagnetic and hydrodynamic properties of gases, statistical mechanics and thermodynamics, the interaction of atoms and radiation, and, through the medium of cosmic rays, even the properties of the atomic nucleus. It contributes to our knowledge of the character and speed of chemical reactions over a wide range of temperatures and pressures. The design and construction of certain components of the equipment require the highest skill of radio and mechanical engineers.

Although several individual scientists in the United States were preeminent in the early development of radio astronomy, there has been no broad, coordinated attack in this country on the basic problems of this field. As a result, other nations (in particular Britain, Holland, and Australia) now lead in this important area. Part of the reason for the lag has been the enormous expense of the tools. However, a more significant factor is the cross-field nature of the research. A truly fruitful program must rest upon a combination of the skills and disciplines listed above.

There are many compelling reasons why the United States should actively enter the field of radio astronomy. The present survey has as its chief objective the bringing together of various scientific groups who have an interest in the field, in order to pave the way for a coordinated attack on the problems, perhaps through the medium of a formal organization, similar to that of Associated Universities Incorporated.

With this objective in view, the Harvard College Observatory Council and scientists from the Massachusetts Institute of Technology have been exploring the possibilities of cooperative effort in this field. Further informal discussions with Dr. Lloyd Berkner, of Associated Universities, as well as with representatives of the Naval Research Laboratory, Columbia University and the Franklin Institute, have demonstrated the breadth of the interest in this field and have pointed to the many benefits that would stem from such collaboration.

One should emphasize both the informal and the exploratory character of this document. Clearly, institutional participation will require the formal approval of the appropriate authorities. However, since all projects of this sort must start somewhere, we hope that this report will stimulate further steps toward the formulation of a concrete program of action, perhaps through the appointment of a committee charged with assessing the field and preparing a coordinated set of recommendations.

1. Scope of Radio Astronomy. In the broader sense, radio astronomy includes much more than the detection of radio emissions from various types of celestial objects. It also involves the reception of signals sent out by radio transmitters and reflected from objects in our atmosphere and in the solar system.

Many of the radio observations reveal phenomena that seem anomalous in terms of the information obtained solely by optical means. We therefore need to interpret them in terms of new models and even new concepts, which may require the development of entirely new theoretical techniques. The success of the project depends critically upon the design, development, and construction of highly specialized equipment. The interpretation of the observational data will contribute to and draw from many related disciplines. In particular, one cannot completely divorce radio astronomy from the closely related field of ionospheric propagation.

2. Radio Emissions from Celestial Sources. Radio emissions fall under two general categories, the first consisting of a "noise" distributed over a wide range of frequencies, and the second consisting of narrowly tuned "emissions" from atomic and molecular sources. The physical processes that produce the noise spectrum are by no means well understood. On the other hand, the general character of the line emission is predictable from the application of accepted theory. The most important source of the line emission is hydrogen gas in interstellar space, responsible for radiation at 1420 megacycles. Further observable emissions are to be expected from deuterium, and also from several molecules, among which OH seems particularly promising.

The sun itself is one of the most interesting and important sources of radio noise. Its noise spectrum consists of a relatively constant background, generally referred to as "the quiet sun". At times of considerable solar activity, we encounter sudden "bursts" of radio noise, with occasional major enhancements known as "outbursts". Although the precise physical processes that produce the radio noise are imperfectly understood, flares, surges, and other active prominences on the sun are apparently responsible for radio disturbances. Solar noise is indeed a new index of solar activity and an important key to the vital problem of solar-terrestrial relationships.

The fact that the sun, a star below the average in temperature, size, and activity, is such a potent radio source, suggests an important new field of investigation in connection with the effects of more active stars on their immediate environment.

It is easy to overlook the moon as a direct radio source. However, evan at the low temperature of its surface, the intensity of its emission at radio frequency is by no means negligible. Such radiation has been detected and measured, thus providing an independent determination of the moon's surface temperature. The temperature proves to be nearly constant with time, an effect resulting from the fact that the radio emission comes not from the visible surface but from a region a few inches below it and well blanketed by a layer of dust. Whether such techniques could also be applied to the determination of the temperatures of Mercury, Venus, or other planets will depend upon the sensitivity of the equipment.

Astronomers use the phrase "radio stars" to denote localized regions of the Milky Way that display high intensity in the radio region. Many of these radio stars have been identified with optically detectable sources, some of them outside our galaxy.

The general noise from our own galaxy provides the best available method of exploring the distant central regions, hidden from our vision by vast clouds of obscuring dust. In certain cases, the radio noise may arise from the interaction of colliding clouds of gas, either in the solar envelope, within our own galaxy, or in a collision between two galaxies. Here the radio observations furnish evidence of aerodynamic conditions quite outside the range accessible in the laboratory.

It should be mentioned that the 1420 megacycle radiation of interstellar hydrogen, by virtue of its Doppler displacement, provides a useful tool for study of the structure of and motions within our galaxy. This radiation comes from hydrogen gas, which outlines the spiral structure of the system.

There have been occasional reports of high-frequency radio noise from the aurora borealis. It is not quite clear, at this moment, whether the noise originates within the glowing clouds or whether it represents garbled fragments of ordinary man-made radio transmissions. In any case, the phenomenon is important and merits further study.

There is little doubt that the ionosphere itself, under certain conditions, provides a source of radio emissions. Most of these, however, would likely be at a frequency close to the "gyro frequency," and would probably be highly absorbed in the upper atmosphere. The phenomenon, however, deserves some attention.

At first sight one might question the listing of the aurora borealis and of the ionosphere among "celestial sources." There are, however, several reasons for the inclusion. First of all, both these regions of the atmosphere derive their properties from a combination of solar ultra violet energy and corpuscular emissions from the sun. Second, physical processes in these regions are similar to those in the outer regions of stellar atmospheres, in gaseous nebulae, or in interstellar space.

3. <u>Reflections of Radio Waves</u>. We here make a distinction between the

crude radio emitters discussed in the preceding paragraph and the direct application of "radar" techniques, wherein a "pulsed" transmission goes to the object in question, and after reflection, returns to a receiver. The transit time of the signal measures the distance of the object. Other characteristics of the radio echo may conceivably provide additional information concerning the nature of the surface, the extent of the object, etc.

Reflection techniques, both for vertical incidence and for oblique incidence, have long been used in exploration of the ionosphere. Although the observations have generally received a conventional interpretation in terms of a model involving horizontal stratification, further study of irregular features within the ionosphere, such as localized clouds, "sporadic E," auroral condensations, etc., should provide important information about the characteristics of the ionized layers. This information should be particularly valuable in the fields of radio communications and meteorology.

Radar exploration of the aurora is also important, though such study cannot be completely dissociated from the problem of the ionosphere. Of considerable importance is the localization of auroras in space, including the possibility of detecting the presence of ion clouds in regions exterior to the earth's atmosphere, before they have excited the luminosity of the aurora itself.

The ionized cap that accompanies a meteor in its flight through the upper atmosphere proves to be an intense reflector of radio waves. Study of such reflections has furnished an important tool, not only for the study of meteors and their distribution in space and time, but also for the determination of the effect of meteoric ionization on the ionosphere and upon the propagation of radio waves. This study may also include reflections from enduring meteor trains, a subject about which little is known. The first laboratory experiments on ionization by artificial meteors have provided extremely valuable ballistic data.

Some eight years have elapsed since we obtained the first radar reflections from the moon. However, there has been no attempt to refine the techniques and get valuable scientific data, such as an improved lunar parallax or a direct determination of the moon's radial velocity. Increased sensitivity of the electronic components and larger antennas effectively enhance our chances of receiving echoes from the sun or from the planets.

4. <u>Equipment</u>. The equipment of radio astronomy requires the coordinated efforts of the electrical engineer, the electronics expert, the radio engineer, and the mechanical engineer.

The wavelengths of the radio emissions are long compared with those of light. In consequence, we must resort to enormous dishes or complicated antenna arrays, in order to obtain the necessary resolving power. The largest precision dish in operation, now located at the Naval Research Laboratory, in Anacostia, Maryland, has a diameter of fifty feet. Larger dishes are projected for various purposes, by far the largest of all, with a diameter of some 250 feet, being the specialized receiver for radio astronomy planned in Manchester, England. The sole restriction on the size of the receiver is that imposed by the difficulties of construction and mounting, since the radio dish is the only astronomical telescope whose useful size is not limited by turbulence in our atmosphere.

The multiplicity of techniques that must be developed and coordinated in order to achieve maximum efficiency will very likely have an important influence on the more general field of high-frequency radio communication.

5. Allied Laboratory and Theoretical Studies. We have already stated that one of the aims of radio astronomy is the interpretation of the physical processes involved in the production and transmission of the radio waves. Thus it will be necessary to develop the applicable theory. In many cases, it has already become clear that one must set up laboratory experiments to determine the important characteristics of atoms, molecules, and their interaction with radiation. In others, detailed theoretical investigations may be necessary. The following list of topics is intended to be illustrative and could readily be extended.

We need to learn much more about the radio emission from ionized gases. Radio emission associated with organized, large-scale relative motions of the gas (e.g., plasma oscillations, magnetohydrodynamic waves, shock waves), is a field which still remains practically unexplored. The observations of the sun clearly suggest that shock-wave phenomena may be closely allied with radio sources. Theoretical and laboratory studies of shock waves in an ionized gas are essential for a proper interpretation of the solar data. Further studies of the coupling between the velocity field and the radiation field are very necessary. They will have an important bearing on basic problems of modern ultraspeed aerodynamics.

The observed polarization characteristics of the radio waves, together with the known association of certain radio emissions with the magnetic fields of sunspots suggest that an understanding of magnetohydrodynamic processes is essential to the interpretation of the physics of radio emission.

For interpretation of chemical reaction rates, means of atomic excitation, electrical conductivity of gases, etc., we need to know more about the physical properties of selected atoms and molecules. Such studies are important for understanding the nature and behavior of the ionosphere, the aurora, the sun, and the interstellar medium, as well as for their direct applications in physics, chemistry, and aerodynamics.

6. Recommendations for a Preliminary Organization. We feel that a small committee of interested scientists should be formed initially to discuss the details of the program, to formulate a working policy, and to make recommendations for future extension of the work. For example,

initial participants, in addition to representatives from Harvard University, Massachusetts Institute of Technology and the other members of Associated Universities Incorporated, should include scientists from the Franklin Institute, Penn State, Naval Research Laboratory, the Carnegie Institution of Washington (Department of Terrestrial Magnetism), and possibly others.

Small sub committees would deal with the individual problems and report back to the main steering committee.

7. Selection of Sites for the Facilities. As a guide in site selection, primary consideration should be given to accessibility. One would recommend that appropriate electronic testing equipment be set up, fully calibrated, and then operated at the various potential sites, in order to determine the best location in terms of freedom from local radio interference.

The council of Harvard Observatory wishes to express the opinion that its facilities at the Agassiz Station (where a 25-foot radio telescope is already in operation) might be expanded to meet the needs of the proposal. If necessary, additional contiguous land could probably be acquired at moderate cost.

Round Hill came under consideration, but appeared to be less advantageous than Agassiz Station for several reasons, including local radio interference, greater distance, and the fact that additional land is not available there.

One would expect that laboratories, technicians and appropriate machine shops would be provided, as needed, at the chosen location.

8. Proposed Scientific Program. The primary objective of the initial organization will be to provide basic facilities for as flexible an operation as possible. As a consequence, the actual details of the program will depend largely on the interests of the participating organizations. The allocation of time for the different programs on the large dishes should be in the hands of a committee on operation, much as is done by Associated Universities Incorporated at Brookhaven at the present time.

The scope of the initial program will depend to some extent on the available funds. However, there should be plans to cover the radio astronomy field as widely as possible by a program that includes solar research, galactic research, selected phases of ionospheric research, and meteor research.

An important aspect of the program should be its accessibility to competent graduate students. Only at Harvard is there at present an academic program in radio astronomy. The limited program of radio astronomy in the United States at the present time clearly results from lack of trained personnel. A major effort should therefore be directed toward the provision of graduate training in this field.

9. Requirements for Staff. To give permanence and continuity to the operation, the organizational arrangement should probably be similar to that of Associated Universities Incorporated. The director and supporting staff would be part of this permanent organization. The participating institutions would provide the scientific personnel. The details should be worked out by a steering committee. One should emphasize, however, that it is extremely important for the success of the operation that a man of high competence be obtained for the post of director.

10. Associated Optical Equipment. It is generally recognized that radio astronomy is by no means completely independent of optical astronomy. To interpret the radio data fully we must make concurrent optical studies.

To provide coordination for the solar studies, for example, a small coronagraph and narrow-band filter are needed for surveying flares, sunspots, and other active solar areas.

As an auxiliary for the interpretation of galactic studies, a Schmidt telescope of medium size is desirable, perhaps with a 30-inch mirror and a 24-inch correcting plate. Harvard Observatory possesses optics for such a telescope and would probably be willing to make them available to the project, especially if Agassiz Station were selected for the site.

To date, the optical and radar studies of meteors have not been coordinated. Harvard Observatory has been operating the so-called super Schmidt meteor cameras in New Mexico. These cameras might be set up at local stations, thus securing the coordination with radio data that is particularly vital in studies of the upper atmosphere.

11. Concluding Remarks. The foregoing study, incomplete as it is, shows that the necessary facilities, because of their enormous expense, probably lie beyond the means of any one institution. This organization of Associated Universities Incorporated has effectively solved a similar problem. The nature of the work in radio astronomy should be well adapted to a similar type of organization. Indeed, because of the many evident parallel relationships, the suggestion that Associated Universities Incorporated should itself support the proposal merits most serious consideration. This document represents an informal exploration of the possibility.

/s/ Donald H. Menzel

Harvard College Observatory
April 13, 1954