40. COMMISSION DE RADIO-ASTRONOMIE

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INTRODUCTION

The Radio-Astronomy Commission has a peculiar role to play in the I.A.U. because of the rapidity with which its techniques are developing into diverse fields in astronomy. These developments pose a problem in transmission of ideas between radio experimenters and astronomers who are each expert in their fields. This problem is accentuated by the fact that a large proportion of those contributing to radio astronomy have been trained as physicists or engineers and not as astronomers. There is need to inform astronomers of the fields in astronomy to which radio is contributing, or can contribute, and to provide clear statements on the experimental and the interpretative uncertainty in the available results. Similarly there is need to inform radio astronomers of relevant aspects of astronomy with which they may not be adequately familiar. This is a liaison job which, at this phase in the development of radio astronomy, Commission 40 should accept as one of its major responsibilities. As radio techniques become familiar in astronomy, it is to be expected that radio observations will progressively be absorbed in the fields of the various other commissions and the field of Commission 40 may narrow towards a consideration of problems which are peculiar to the use of radio techniques. In pursuance of this end a symposium on radio astronomy was held at Jodrell Bank in 1955, and the Proceedings of this Symposium now form an important contribution to the literature of radio astronomy. In 1958, just prior to the I.A.U. General Assembly, a second symposium will be held in Paris under the joint auspices of the I.A.U. and U.R.S.I. The proceedings of this symposium* will provide a comprehensive and up-to-date account of the main aspects of radio astronomy in 1958 with which this report should not attempt to compete. In place of a detailed account it appears that a proper purpose would be served by outlining in this report the fields in astronomy to which radio is contributing and, when practicable, giving a broad assessment of the current status of that contribution.

An interesting new branch has recently developed in radio astronomy: the study of 'whistlers' and allied phenomena, as a means of gaining information about electron densities and magnetic fields in the space surrounding the Earth. Turning to more material objects in the solar system, radio methods are now beginning to make significant contributions to knowledge of surface conditions on the Moon and planets and have at last been applied to the precise measurement of an astronomical distance, the distance to the Moon.

Solar radio astronomy has been going through a phase of development of new methods and equipment and it is probable that substantial progress in understanding solar phenomena may soon follow from the utilization of resulting new observations.

Hydrogen-line studies continue to occupy a place in radio astronomy which is outstanding for the detailed physical information being obtained. The study of the general distribution of interstellar gas in our own and external galaxies now depends more on 21-cm line observations than on optical ones. Further, 21-cm studies have established a result which is fundamental to astronomy and indeed to physics: the red-shift is identical at optical and radio frequencies. Studies of the continuum in the galactic radio

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spectrum now have two focal points of interest. The mechanism of origin of the non-thermal component is now believed to be the synchrotron mechanism so that the sources of this component may well also be the sources of cosmic rays; and H II regions are now being studied both in emission (at high frequencies) and in absorption (at low ones).

In the field of cosmology there has been a halt. Previously announced radio results which appeared to invalidate the steady-state continuous-creation hypothesis concerning the universe are now believed to be invalid and the point is now non-proven. More certain knowledge must await the construction of more powerful tools.

We now review these studies in approximate order of increasing distance from the Earth.

THE SOLAR SYSTEM

Meteors

The radio study of meteors is a field in which radio and optical observations are accepted as of comparable importance. The most interesting recent radio development is probably the use of increased sensitivity giving meteors down to about optical magnitude 13 at which the observed sporadic rate is up to about 100 per minute [1, 2].

Whistlers

In the space just outside the ionosphere a new method, the study of 'whistlers', promises to throw light on the electron density and magnetic field out to distances of a few Earth radii and hence possibly to elucidate the problem of the ejection of corpuscles by the Sun. 'Whistlers' are radio disturbances in the frequency range 1–20 kc/s which are emitted by lightning flashes and propagated through the ionosphere, which is grossly over-dense at these frequencies, only along the direction of the Earth's magnetic field. They are then guided along lines of force to the magnetically conjugate points on the other hemisphere. The selective delays which the various frequencies suffer depend on electron density and magnetic field conditions along the path, and observations of these delays should yield information about the physical conditions. The present status is that the mode of propagation is established beyond doubt and the observations imply that the mean electron density in the vicinity of the Earth is high, of the order of 1000 per c.c., and shows substantial variations in space and time [3].

Low-frequency emission

It is also suggested that certain low-frequency radio disturbances originate in and above the upper parts of the ionosphere under the influence of high-velocity particles, or clouds of these, incident from outside. Roger Gallet [4] has described certain observed disturbances ('hiss', 'hooks', etc.) in the frequency range in which 'whistlers' are observed which he ascribes to such a process. At a somewhat higher frequency, in the hundreds of kc/s range, Ellis [5] has suggested that radiation which he and Reber observed may be due to Cerenkov radiation from fast electrons such as those that occur in the aurora. Both these suggestions may lead to the elucidation of the problem of conditions in interplanetary space but at present are in the speculative stage.

The Moon

The Moon can be observed by radar or by using thermally emitted radio waves. Observations of the latter, which led to the suggested layer of dust overlying a solid surface, have been refined and extended to other frequencies so that the time now appears ripe for a revaluation based on data over a significant frequency range. Observations of echoes using short pulses described by Trexler, Yaplee, and Lovell at the U.R.S.I. General Assembly have led to a change in perspective regarding the degree of elongation of the echo due to its return from both near and far parts of the visible surface. It has been shown that echoes show a rapid rise followed by a decay to a low value in the remarkably short time of about 300 μs, which corresponds to a radial distance of only 30 miles [6, 7].

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This implies that the Moon is remarkably smooth, incidentally sufficiently smooth to return clearly intelligible speech from voice transmissions directed towards it. Probably more important to astronomy is the first extra-terrestrial application of the great precision in distance measurement which is possible using radar. Yaplee [7] measured the distance to the near point on the moon, which of course varies with time, to an accuracy which he estimated to be half-a-mile, or 2 parts in 10^6. It is not clear whether such observations of distances to the Moon can be used to improve the accuracy of the astronomical distance scale; similar observations of distances to planets, which however require much higher power or sensitivity, should certainly do so.

It is also of interest that the time delay depends slightly on the electron density along the path, the delay increasing sharply with decreasing frequency, so that measurements of the difference in time delay at appropriate different frequencies could be used to measure the mean electron density between the Earth and the Moon. At 20 Mc/s, for example, the selective retardation for an electron density of 1000 per c.c. is about 1 part in 10^4 which appears to be well within the potential experimental uncertainty. This observation is distinct from that of the well-known Faraday rotation of the plane of polarization, which arises mainly in the ionosphere, and can be used to measure the total electron density in the ionosphere. Observations were also reported at the U.R.S.I. General Assembly of a very puzzling effect. At frequencies as high as 400 Mc/s several observers of Moon echoes reported deep fades of 10 or 20 db over periods of an hour or so which were not due to rotation of the plane of polarization.

Planets

Radio waves from planets fall into two distinct categories: high-intensity variable emission due to some form of electrical disturbances, and thermal emission. In the first category radio emission from Jupiter has continued to be studied without positive conclusions being reached as to its nature. Nor are the basic observations yet agreed on. There is agreement on the spectrum showing a sharp decrease in intensity at frequencies above 20 Mc/s, on the typical occurrence of groups of bursts of seconds duration, and on a strong tendency to recurrence of periods of activity at intervals equal to the rotation period (System II) of Jupiter. There is disagreement as to the occurrence of short (order of $0^s.01$) bursts, and on the question of whether the recurrence tendency persists over periods of the order of six years. If true, the latter is interpreted as showing that the areas in which disturbances originate are anchored in the solid surface of Jupiter [8, 9]. Somewhat similar radio waves have been reported from Venus [10], but these have not yet been confirmed by other workers. Observation in the wave-length range where these planetary emissions have been observed is now exceedingly troublesome owing to severe terrestrial interference which is bad at times of high sunspot number.

In the second category, presumed thermal emission from Venus, Mars, and Jupiter on a wave length of 3 cm has been observed. Observations gave an apparent temperature of Venus which is much higher than the temperature deduced from optical observations so that there is a discrepancy to be explained [11, 12].

Comets

Observations of radio emission from a comet were reported at the U.R.S.I. General Assembly by Kraus [13], Coutrez [14] and Becker [15]. Numerous other observers reported negative results. The reason for these differing results is not clear.

THE SUN

Solar radio astronomy is in an equipment-development phase so that major discoveries may be expected soon. In consequence this report will be restricted to a brief statement on new equipment and a mention of two stimulating observations, incidentally both from Meudon. The first of these is the recognition by Boischot of a new type of burst (Type IV);

the second is the surprisingly close correlation found by Denisse and Kundu between the intensity of 10-cm solar emission and that of the radiation ionizing the E-region of the ionosphere.

Observations of the dynamic spectra of solar bursts have been extended in frequency range from the original 40–240 Mc/s up to 600 Mc/s by the installation of two new spectrometers covering the range 100–600 Mc/s at Fort Davis (Harvard) and at Ann Arbor (University of Michigan) respectively. These should help in understanding the way in which bursts in the centimetre and metre wave-length ranges are related but do not yet provide sufficient frequency coverage. Higher frequency spectrograms are also required.

Previous observations of burst spectra have led to hypotheses suggesting that bursts originate in moving disturbances on the Sun. These hypotheses could be checked by directional observations and such observations are now being carried out (Radiophysics Laboratory, Sydney) using a swept-frequency interferometer [16]. This instrument gives the instantaneous position, and hence movement if any, size, and polarization of bursts as a function of frequency.

Turning to high-resolution equipment, a 169 Mc/s, 32-element Christiansen interferometer having a knife-edge beam of width 3′ was installed at Nançay (Meudon Observatory) in 1956 and is in regular use [17]. In contrast to the two-element interferometer above, it can give details, though still one-dimensional, of a complex distribution of brightness, but it is less able to cope with sporadic short-duration phenomena. At Sydney (Radiophysics Laboratory) an instrument having a pencil beam 3′ in diameter, which scans the Sun television fashion, began recording in 1957. It operates on 21 cm and provides, for the first time, two-dimensional radio pictures of the Sun [18]. Like the Nançay instrument, it too is ill-adapted to observing short-duration phenomena, but these are less frequent on the shorter wave-length.

Two further investigations now being actively pursued in several places are observations at millimetre wave-lengths which should provide valuable information relating to temperature and density in the chromosphere and, at the other extreme in the solar atmosphere, observations of heterogeneity in the corona based on the varying obscuration of the emission from the Crab nebula as it is progressively occulted by the solar corona.

GALAXIES

Spectral line observations

Twenty-one centimetre hydrogen line observations continue their prominent role in delineating the spiral and other structure in the galactic disk and in revealing the general distribution of interstellar gas and its relation to stars in our own and other galaxies. They have also shown a most interesting new phenomenon—what appear to be spiral arms near the galactic centre which are in rapid motion outwards.

The Leiden observations of general spiral structure in the Galaxy which were outlined in 1955 have now been described in detail [19]. Corresponding southern-hemisphere observations taken in Sydney have been completed and partly reduced, and the overall picture is being studied jointly by Sydney and Leiden workers. The completion of these studies will mark the end of an outstanding phase in galactic astronomy: the first broad delineation of the distribution of neutral interstellar hydrogen, H I regions, in the disk of our Galaxy. But the observations are still mere samples and the interpretation is in terms of a rotational model which is in obvious need of refinement. The completion of the first phase should be seen as a challenge to astronomers to fill in the detail using the best possible combinations of radio and optical observations. Further, the whole of the present work refers to the galactic disk. Hydrogen has been observed outside this disk but our present knowledge of it is rudimentary.

In addition to completing a crude picture of the spiral structure, the Leiden and Sydney observations gave important information about the shape of the thin disk, whose thickness to half-density is about 250 pc, in which the neutral hydrogen is concentrated.

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The disk is remarkably flat in the region within about 6 kpc of the centre but shows substantial deviations from this plane in the outer regions. The flat central region appears to give a really sound reference plane for dynamic and structural studies of the Galaxy. Some of the outer deviations appear due to the influence of the neighbouring Magellanic Clouds and may provide clues on the nature of interactions between galaxies [20]. The relative proportions of neutral hydrogen and stars in the disk of our Galaxy have been found to increase greatly on going from the central to exterior regions [21], conforming with the distribution found years ago for the Magellanic Clouds and recently for M 31 [22]. The ratio of hydrogen to total mass in our Galaxy and in M 31 is estimated as about 1%. Estimates for other galaxies range from about 30% for the Clouds, through about 10% for M 33 and M 81, down to the above value of 1% for M 31 and our Galaxy.

The unexpected outward-moving spiral arms were reported by van Woerden, Rougoor and Oort [23]. They found, in a direction close to the galactic centre, a peak in the line-profile indicative of a concentration of hydrogen approaching us with a velocity of about 50 km/sec. This peak showed continuity over a series of longitudes indicating that the concentration was probably a spiral arm. Moreover the same peak appeared in absorption in the spectrum of the radio source Sagittarius A, the one which lies in the direction of the centre of the Galaxy. Thus the arm lies between us and Sagittarius A. Further, another arm receding from us with a velocity of 100 km/sec was observed which, from the lack of obscuration, lies beyond Sagittarius A. From such evidence it was inferred that Sagittarius A is close to the centre of the Galaxy and the two arms are rapidly moving away from the centre—a result which may be of fundamental importance in the study of the dynamics of galaxies.

With the introduction of larger, higher resolution, radio telescopes it is becoming feasible to observe smaller complexes in the Galaxy and the distribution and movement of hydrogen in stellar associations and galactic clusters is being studied [24].

No spectral line other than the 21-cm hydrogen line have been observed in the cosmic radiation; attempts to detect deuterium [25] and OH [26] lines were unsuccessful.

Continuum observations

The continuum includes radiation originating in at least two distinct ways: thermally, in free-free transitions in ionized interstellar gas, H II regions, and, non-thermally, by what is probably the synchrotron mechanism in which relativistic electrons spiralling in magnetic fields emit light and radio waves. The initial evidence for the latter process, the observed linear polarization of the light from the Crab nebula and from NGC 4486, has now been reinforced by radio observations on 3 cm by Mayer and on 10 cm by Kuzmin and Udaltzov of linear polarization of a few per cent in the radio emission from the Crab. Longer wave-length observations have yielded negative results. It is further reported by Rasin [27] that the radio emission in regions remote from the Milky Way shows plane polarization ranging from 2·5–5% at 1·45 m. to about a quarter of this at 3·3 m. In regions where this process occurs cosmic rays are also likely to be generated. There may also be other unidentified mechanisms. The spectra of the above components are such that the non-thermal component is dominant at intermediate frequencies, e.g. 100 Mc/s, while the thermal one becomes prominent at high frequencies, e.g. 1000 Mc/s. At much lower frequencies, e.g. 20 Mc/s, the non-thermal emission is dominant but H II regions appear in absorption. Thus at high and at low frequencies radio observations yield information about H II regions, and studies of the non-thermal component are likely to be related to the origins of cosmic rays and to cosmic magnetic fields and turbulence.

Turning to observation, we observe over the sky a number of discrete sources and an unresolved background of radio emission. This emission is due to at least four distinct sources: (1) an extragalactic contribution including both discrete sources and background; (2) a very widely distributed, probably nearly spherical, source of non-thermal galactic emission from which is inferred the existence of a galactic 'corona'; (3) a system of non-thermal emitters concentrated in the galactic disk, and (4) a system of H II regions in the galactic disk. The problem of sorting out these various sources is a central one to radio astronomy.

The evidence for a galactic corona comes from our own and external galaxies. In our Galaxy, in regions remote from the Milky Way, the background appears not to be due to unresolved point sources and is distributed as if it arose in a uniformly emitting sphere of radius extending well beyond the Sun [28]. This distribution is distinct from that of any known optical objects, and taken in conjunction with the synchrotron mechanism hypothesis, suggests the existence in our Galaxy of a corona of relativistic electrons and magnetic fields [29, 29a]. This conclusion is supported by the observations of the tendency for the radio emission from external galaxies such as M 31 to extend over greater areas than does their light.

It is not yet known whether the non-thermal component of the disk emission is due to the integrated effect of discrete sources or whether there is, in addition, a semi-uniformly distributed contribution. It is now clear that a substantial part of the total emission from the disk is of non-thermal origin [30].

In optical astronomy the term 'H II region' is used to denote a region of ionized interstellar gas. In radio astronomy a further sub-division is required. In some regions of relatively dense ionized gas, e.g. the Orion nebula, the radio emission appears to be mainly, perhaps exclusively, due to thermal emission; in others, e.g. the Crab nebula, the emission is mainly non-thermal. There are also presumably regions in space, e.g. the galactic corona, where very highly rarefied gas is completely ionized but quite invisible optically. There is clearly danger of ambiguity. It is suggested that, following current practice, radio astronomers restrict the term H II region to the relatively dense, thermally emitting, regions and use plain-language terms for the others.

Radio observations at high frequencies show a large number of optically known H II regions, but, without such optical observations, the distinction between a thermal and a non-thermal source must be based on the spectrum. The distinction is complicated by the uncertainty as to the spectrum of non-thermal sources. At low frequencies, however, the distinction is rather more clear cut. Shain [30] has shown at 20 Mc/s that near H II regions gave deep minima in the background of non-thermal emission and suggests that these minima may give a much more sensitive indication of H II regions than do optical observations.

EXTERNAL GALAXIES AND COSMOLOGY

The discovery that many radio sources are external galaxies, and that at least one, Cygnus A, is so powerful a radio emitter that it should still be detectable on currently available equipment up to a distance for which the red-shift is 0·8 c has stimulated the hope that the study of radio sources may contribute to cosmology. A major difficulty is that a simple observation of a radio source gives no indication of its distance. It may be near and a weak emitter or far and a strong one and, to make this worse, the dispersion in emission between known sources is enormous, much more than $10^6:1$. The direct approach of studying the variation of flux density or other useful property with distance for intrinsically similar objects is not yet applicable. The method which has been applied is the statistical one of studying the distribution of flux densities among sources remote from the galactic plane, which are assumed to be largely external galaxies. In a static Euclidean universe in which the source density is constant this distribution would follow a $-3/2$ power law. Deviations from this distribution indicate either irregularities of density or cosmological effects. The Cambridge '2 C' survey on a frequency of 81 Mc/s showed a gross departure from this $-3/2$ law and Ryle and Scheuer in 1955 claimed that this indicated a major cosmological effect, an increase in the volume density of, or average emission from, radio sources at vast distances. At that time Pawsey stated that the Cambridge results did not conform with preliminary results obtained by Mills in Sydney using a Mills Cross, an instrument of much higher resolving power. This discordance has since been fully confirmed by Mills and Slee, only a small proportion of the strong sources agreeing in the two surveys. Mills and Slee [31] attributed the discrepancy

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to confusion effects in the Cambridge survey due to the unresolved background of faint sources on an instrument of inadequate resolution. The author believes this criticism of the Cambridge work to be correct and the Cambridge 2 C source-counts invalid [32]. The Cambridge workers have repeated their survey, the new survey being designated '3 C', on a frequency of 160 Mc/s. At this frequency they have four times the resolution and should be able to recognize four times as many sources without confusion. They now find one-third of the sources in agreement with Sydney [33]. Even now the predicted recognizable number [32] is only about 100 per steradian which is actually about one-third of the number in the Sydney catalogue. Hence there are grave doubts still about the weaker sources in the 3 C catalogue. At the same time there is no confirmation of the Sydney results, which urgently need independent checking.

Mills and Slee's catalogue, like those of Cambridge, shows an apparent excess of faint sources, though much smaller than the Cambridge excesses, but Mills and Slee point out potential errors in their counts which could account for this effect. Thus the Cambridge results, which appear to show the effect obviously, are probably invalid, and the Sydney ones, though they seem to go considerably deeper than the Cambridge ones, do not go far enough to yield results greater than their own experimental uncertainty. The cosmological effect is non-proven from the source counts. The next step requires observations which will reliably yield greater numbers of sources. But an absolutely indispensable preliminary is a careful study of the confusion problem so that methods may be employed which yield reliable results.

Ryle and Scheuer also supported their conclusion from data on the statistics of amplitude variations in their records. The 81 and 160 Mc/s observations both support the thesis [33]. This argument is indirect and it is difficult to assess the effect of the various assumptions concerning such things as source sizes, and lack of clustering of sources, which have to be introduced to reach a conclusion. It should be pointed out that a method based on the simple statistics of flux densities will be insensitive to cosmological effects if, as appears probable, there is a large dispersion in the absolute magnitudes of observed sources. Cosmological effects on the further ones would be diluted by the nearer ones.

Leaving the question of source counts there is another quantity which is of cosmological significance, the background surface brightness due to the integrated effect of all extragalactic objects. The fact that the sky is much darker than the typical sources, as is the sky optically between stars, indicates the operation of a limiting factor, which may well be cosmological. Unfortunately this background radio brightness is difficult to determine because the measured quantity in any direction is the sum of the extra-galactic and a galactic contribution and the latter has to be estimated indirectly [28]. The measured value is of course an upper limit. An interesting new method has been proposed by Shain [34]. At a low frequency, e.g. 20 Mc/s, a large H II region is essentially opaque. If, then, an H II region existed outside our Galaxy the difference in surface brightness between the region and its surroundings should be due to the cutting off of the extragalactic background, with a small correction for thermal emission from the region itself. Now H II regions do not occur in intergalactic space but the region 30 Doradus in the Large Magellanic Cloud can be used with the added complication that it cuts off the radiation from that part of the Cloud beyond the H II region. However this can be estimated on the assumption of equality between the near and far sides. Shain has not yet given quantitative results.

It is clearly desirable that some sort of a distance indicator for unidentified radio sources should be found. One possibility is angular size. Current results indicate, among external galaxies which are identified as radio sources, a relatively small spread in linear dimensions. Hence sources of small angular size are probably distant ones. A search for sources of small angular size is being undertaken at Manchester and Sydney.

A much more direct method is the use of the red-shift and it was a result of major importance when Lilley and McClain [35] showed that Cygnus A showed a faint absorption line in the 21-cm line of hydrogen which was shifted in frequency in the same ratio as the light from the source. This implies a halo of neutral hydrogen surrounding the strongly

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emitting regions in Cygnus A. But it also emphasized the difficulty of measurement. Cygnus A is the second strongest source in the sky. Using a 50-foot aerial the absorption was only just detectable. It suggests that red-shifts will only be measurable for sources which are 10 or 100 times more intense than necessary for simple recognition.

Lilley and McClain's observation however is of basic importance to physics and astronomy. Interpretation of the red-shift as a Doppler-shift is a hypothesis. Evidence that the Doppler displacement law is accurately obeyed at the ends of the tremendous frequency range between radio and light is one more scrap of evidence consistent with the Doppler interpretation [36].

Red-shift observations have not been restricted to a single galaxy; 21-cm emission from, first the Coma cluster, and then clusters in Hercules and Corona Borealis, has been reported by Heeschen [37]. The masses of hydrogen were estimated from the observations and imply vast masses of neutral hydrogen either in the galaxies or in the space between. Here then is a potential method for exploring the gas content of inter-galactic space.

TECHNICAL DEVELOPMENT

The period since 1955 has seen a great expansion of facilities devoted to radio astronomy and some very important technical developments. The new facilities in use at the time of writing include 20–25 m diameter steerable parabolic aerials in Holland, Western Germany and the U.S.A., and the great 75-m instrument just completed at Jodrell Bank. Numerous others in the range about 25 m are being constructed in the U.S.A., Canada, and Germany. Two more giants, a 42-m one in the U.S.A. and a 70-m one in Australia are also projected.

New aerial forms

The above radio telescopes are fully steerable paraboloids of revolution. Other means for attaining large size at less cost were reported at the U.R.S.I. General Assembly. These include: (1) a reflector, 150 m in the long dimension, composed of individual adjustable segments of paraboloids of revolution (Korolkov, Pulkovo); (2) a fixed paraboloid, 110 × 22m, with a horizontal beam steered by tilting a plane mirror which lies in the beam (Kraus, Ohio State University); (3) a fixed cylindrical paraboloid, 200 × 130 m, pointing upwards, fed by a line source which may be used to steer the beam in one dimension by phase adjustments (Swenson, University of Illinois). An alternative, which has been described [38] but not tried, utilizes a fixed primary mirror of spherical form combined with a much smaller secondary mirror which suppresses aberrations. The beam is steered by moving the secondary mirror. Thus the present position is that the fully steerable paraboloid is the only generally accepted design for a very large aerial but numerous expedients to overcome its limitations are being studied.

Enhanced directivity devices

Important developments have taken place in the field of enhanced directivity devices, i.e. those which give high directional discrimination without correspondingly great area.

In Nançay the Meudon group have developed at 169 Mc/s a 32-element Christiansen interferometer nearly 2 km in length [17]. This has multiple 3′ knife-edge beams and is used primarily for observations of the Sun. It has been in use for about a year with excellent results. A notable technical feature is the use of special pre-amplifiers near the individual aerials, which have maintained the necessary high degree of phase and amplitude stability. The implication is that base lines could be still further extended.

In Sydney an instrument which we may term a radio-heliograph has been completed, combining the principles of the Mills Cross and the Christiansen 32-element interferometer [39]. It gives multiple pencil beams of 3′ at a wave-length of 21 cm which are used to scan the Sun television-wise and so give actual radio pictures of the Sun. A similar instrument, working on 10 cm, is under construction at Stanford University.

In Cambridge a radically new form of radio telescope, based on the combination of a relatively small movable element with a long thin array, is being constructed [40]. A number of interference patterns are obtained corresponding to different positions of the smaller unit. The required distribution of radio brightness over the sky is obtained by elaborate computation which is to be done on an electronic computer. This method is intermediate between that of O'Brien, who used a simple two-element interferometer with a wide range of orientations and spacings, and the Mills Cross which uses two long thin fixed arrays. One Cambridge unit will operate on 1·7 m, the array will be 420 m long, and the movable aerial 70 m in extent. It will give an effective beam $25' \times 35'$. The enunciation of the principle, which Ryle describes as 'aperture synthesis', is very stimulating. It is not clear at this stage what practical difficulties will be encountered. The immediate question concerns the effects, and the recognition, of sundry errors of measurement. In such an indirect system such factors could be serious.

Receivers

On the receiving side there have been two outstanding advances. Drake and Ewen [12] have successfully used a travelling wave tube, with its potentially very great received frequency band and corresponding high sensitivity, for reception of the continuum. Using a band-width of 1000 Mc/s and a time constant of 80 s at a frequency of 8000 Mc/s they realized a fluctuation level of only $0\overset{\circ}{.}01$ K. With this sensitivity, which is one or two orders of magnitude better than previous practice, they were able on a 28-foot aerial to record radiation from Jupiter and Saturn and from two planetary nebulae.

The second concerns the preliminary development of a solid state MASER amplifier which it is hoped will realize noise temperatures of tens of degrees Kelvin, instead of the thousands of presently available receivers. This has not yet reached the stage of application to radio astronomy but laboratory developments appear very hopeful. Current experiments are with narrow band-widths at which the potential decrease in noise temperature, in applications to the continuum, gives a sensitivity of the same order as a travelling wave tube with its wide band-width. But in application to line radiation the MASER should show an enormous gain. And it is possible that the MASER may be developed to give both low noise temperature and wide band-width.

BIBLIOGRAPHICAL NOTES

Bibliographies

The excellent Cornell 'Bibliography of Extra-terrestrial Radio Noise' has fallen behind in publication but it is hoped to revive it. It is complete with full abstracts to 1951; from 1952–56 a list of titles has been issued. Those interested in obtaining copies should communicate with the editor, Martha E. Stahr-Carpenter, Department of Astronomy, Cornell University, Ithaca, New York, U.S.A.

A further bibliography for the years 1954–56, classified under the U.D.C. system, has been prepared by Marjory McKechnie, F. J. Kerr and C. A. Shain and issued by the Radiophysics Laboratory. This includes very brief abstracts. Those interested in obtaining copies should communicate with the Chief, Division of Radiophysics, C.S.I.R.O., University Grounds, Sydney, Australia.

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Report of Meetings

PRESIDENT: J. L. Pawsey.

SECRETARY: B. Y. Mills.

The Commission held four meetings:

1. 14 August. Business.

2. 14 August (jointly with Commissions 10 and 11). To hear a report by M. G. J. Minneart on highlights of the solar sessions at the Paris symposium on Radio Astronomy. (See I.A.U. Symposium No. 9, *Paris Symposium on Radio Astronomy*, published by Stanford University Press.)

3. 16 August. For presentation of scientific papers which had not been read at Paris owing to the absence of the authors.

4. 19 August (jointly with Commission 33). To hear and discuss the report of Commission 33 *b* on the revision of the galactic co-ordinate system (see report of Meeting under Commission 33, p. 530).

Meeting of 14 August

The following items were discussed:

1. *Draft Report.* A statement was read by F. G. Smith covering some aspects of the recent work of the Cambridge group not included in the President's report. It was resolved that the statement should be included in the report of the meeting. (The reader is referred to the proceedings of the Paris Symposium for a general discussion on the highly controversial questions raised by Dr Smith.) See Appendix 1.

2. *Frequency allocations for radio astronomy.* The report of a sub-committee was presented by F. G. Smith (see Appendix 2). It was recommended that an approach to C.C.I.R. on this question should be made conjointly with U.R.S.I. and if possible that the case should be presented by a radio astronomer. Commission 40 passed the resolution included in the Appendix which was later passed by the General Assembly (see Resolution no. 65).

3. *A standard sequence of radio sources.* C. L. Seeger presented a report prepared by a sub-committee—see Appendix 3. The recommendations were adopted by Commission 40.

4. *Predictions of occultations of discrete radio sources.* A sub-committee report, Appendix 4, on the question of continuing the Greenwich predictions of occultations of discrete sources, was presented by Mrs Sadler. The Commission thanked Mrs Sadler for her past work in preparing predictions of occultations and accepted her offer to continue the work. It appointed a continuing sub-committee, comprising Mrs Sadler, D. W. Dewhirst (convenor) and C. L. Seeger, to decide on the future form of predictions and to make changes when they considered it desirable. Radio astronomers interested in this service should communicate with the appropriate member of the sub-committee (see Appendix 4).

5. *Bibliographies of radio astronomy.* As mentioned in the President's report, the Cornell Bibliography has fallen behind. M. Cohen reported for Mrs Stahr-Carpenter, the editor, that financial support had been obtained from the U.S. National Science Founda-

tion for a further series of publications of the Cornell Bibliography. It was planned to issue quarterly lists and yearly supplements. In addition, preparations had already been made to bring the existing series up-to-date by issuing bibliographies for the years 1953–57 at the rate of two or three a year, not necessarily in sequence. Mrs Stahr-Carpenter requested that reprints of papers on radio astronomy be sent to her regularly. If any institution not on the present distribution list requires copies of the bibliography, they should write to her at Cornell University, Ithaca, N.Y., U.S.A.

6. *Paris Symposium on Radio Astronomy*. F. T. Haddock reported briefly on behalf of the Organizing Committee (see Appendix 5). Speakers generally agreed with the points raised in this report. It was decided to make no recommendations about future symposia now but to wait and see how circumstances develop.

7. *Arrangements for publication of I.G.Y. solar data*. Y. Öhmann, retiring I.G.Y. reporter for solar activity, outlined decisions taken recently by C.S.A.G.I. for the publication of I.G.Y. data on solar activity. In the absence of S. F. Smerd from the C.S.A.G.I. meetings, numerous details concerning solar radio emission were left in abeyance and these questions were referred to Commission 40. The Commission appointed a sub-committee consisting of M. A. Ellison, I.G.Y. Reporter on Solar Activity following K. Y. Öhman; S. F. Smerd, Editor, I.G.Y. solar radio emission data; J. F. Denisse; F. T. Haddock and a radio astronomer from U.S.S.R., to be co-opted, to formulate detailed plans concerning these points; S. F. Khaikin was later co-opted.

8. *World List of radio observatories*. At the Dublin General Assembly, Commission 40 requested its President to prepare a list of radio observatories throughout the world. The President reported that he had prepared a list giving, for each radio observatory, (i) the name and address, (ii) names of the persons in charge of the radio work and senior permanent staff, (iii) principal investigations, and (iv) notable equipment. A limited number of copies of a draft list were made available at the meeting and help requested in checking this. The revised list, which contains particulars of sixty-two radio observatories in twenty-one countries, will be published shortly and circulated in an I.A.U. Circular.

Meeting of 16 *August*

At this meeting an opportunity was given for the presentation of papers which had not been given at the Paris Symposium. Authors and titles are given below:

V. L. Ginzburg and V. V. Zhelezniakov, 'On the Mechanisms of Sporadic Solar Radio Emission'.

O. E. Rydbeck, 'On the Interaction between Electromagnetic Waves and Space Charge Waves in an Inhomogeneous Medium producing Radiation'.

V. Ikhsanova, 'Radio Observations of the Sun with the Large Pulkovo Radio Telescope'.

G. Gelfreich, D. Korolkov, N. Riskov and N. Soboleva, 'On the Regions over Sunspots as studied by Polarization Observations on Centimetre Wave-lengths'.

G. Gelfreich, V. N. Ikhsanova, N. L. Kaidanovsky, N. S. Soboleva, G. M. Timofeeva, V. N. Umentsky, 'Bursts of Microwave Solar Radio Emission Associated with Solar Flares'.

T. Hatanaka, 'Linearly Polarized Component in Outbursts at 9500 Mc/s'.

R. Coates, '4 mm Bursts Associated with Solar Flares'.

M. Laffineur, 'Haute Provence Radio Interferometer'.

E. Chvojkova, 'On the Geometry of Radio Propagation'.

N. Kardashov, 'On the Possibility of Detection of Another H-line'.

N. Sen, 'Effects in a Shock Front with Application to Solar Radio Noise'.

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APPENDIX I. STATEMENT BY F. G. SMITH ON ASPECTS OF RECENT CAMBRIDGE WORK

The writer of the *Draft Report* of Commission 40 has to perform the difficult function of giving an assessment of the current status of the various branches of radio astronomy, and as Dr Pawsey has pointed out, it is difficult to be up-to-date in a report written about nine months before the joint I.A.U.–U.R.S.I. Symposium in Paris. I think it would add materially to the report if remarks are made here on subjects where the general view has already appreciably changed.

I would refer primarily to the situation regarding the observations of discrete radio sources, and to the cosmological implication of these observations. Although everyone must agree with the remark that the present suggestions on cosmological theory are non-proven, it is necessary to record that the observational results leading to these conclusions are by no means invalid, and are supported by recent work. Two types of observations are concerned: those involving discrete sources individually located and catalogued, and those concerned with sources of smaller intensity which combine to produce a statistically confused record. Surveys of discrete sources may be limited in usefulness either by confusion or by side-lobes, or possibly by both. It has been apparent for some time that the 2C survey was severely limited by confusion: in fact 50×10^{-26} flux units is the useful lower limit for this survey rather than 25×10^{-26} as suggested in the catalogue. I would emphasize that the papers by Ryle and Scheuer in which cosmological conclusions were drawn depended not so much on this catalogue as on the analysis of the confused records themselves, by a method which Scheuer has explained in great detail, and which was widely discussed at the Paris symposium.

A fair measure of understanding of the problems of the different methods of observation was reached at the symposium; considerable help in this came from the 3C survey, mentioned in the report, and also from some early results from the new interferometer at the Mullard Observatory. The 3C survey gave very similar results to those of 2C in the statistical analysis of confused records, and has also given a catalogue of about 450 discrete sources whose positions are accurately determined. The experimental evidence which led to the cosmological conclusions is completely supported. There is, however, room for discussion of the effects of diameters on the interferometer record, although even here there is experimental evidence that there are no appreciable effects on the present records. We may hope that the differences between the discrete sources listed in 3C and those of Mills's catalogue may soon be resolved with the help of the new Cambridge radio telescope, and with Mills's new interferometer.

There are three small observational matters which might well be reported here, as they were published at about the time the report was written. First, in the section on comets, it should be mentioned that a search was made for diffraction in the tail of Comet Arend-Roland, resulting in an upper limit on electron density. Secondly, in the section on the continuum, Thompson's work has shown that plane polarization may possibly be present at 160 Mc/s, but at a level of only 1 %. Thirdly, it is now possible to assess more directly the merits of the method of 'aperture synthesis', as this method was successfully used in a radio telescope for a pencil beam survey by Blythe.

APPENDIX 2. FREQUENCY ALLOCATIONS FOR RADIO ASTRONOMY

Resolution (no. 56) adopted by the General Assembly of the International Astronomical Union on 20 August 1958, with supporting argument

The International Astronomical Union supports the suggestion that U.R.S.I. should provide C.C.I.R. with the detailed requirements for frequency bands for radio astronomy.

The International Astronomical Union asks C.C.I.R., with the co-operation of U.R.S.I., to treat this matter with the greatest urgency, and to take the necessary steps to obtain these frequency bands at the forthcoming International Conference on Frequency Allocation.

The I.A.U. takes note of the recommendation of U.R.S.I. at the 12th General Assembly in Boulder concerning the provision of protected frequency bands for radio astronomy, and recognizes that C.C.I.R. has already given some consideration to this problem.

The I.A.U. now draws attention to the extreme urgency of this matter in view of the rapidly increasing difficulties being encountered by radio observatories. The whole future of radio astronomy, involving as it does both pure astronomical research and research into radio propagation, depends on the provision of protected frequency bands in the forthcoming International Conference on Frequency Allocation.

The necessity for providing a clear band in the neighbourhood of the 21cm line radiation from neutral hydrogen is clearly recognized, but it is apparent that contributions of the highest importance can be made by observations at frequencies widely spread through the radio spectrum. Studies of the galaxy, of the extra-galactic nebulae, and of radio sources in the distant parts of the universe inaccessible to other means of observation, are particularly threatened by the extension of radio transmissions throughout the region of metre wavelengths. At shorter wavelengths, the advantages of great angular resolving power and of the very low noise level promised by new techniques can only be exploited in protected frequency bands. Unless it is possible to provide bands in which continuous observations may be made in complete freedom from interfering signals, this work may become impossible, and the development of radio astronomy will be halted.

Detailed recommendations are now being prepared by Commission V of U.R.S.I., based on the following minimum requirements for radio astronomy:

1. For observations of hydrogen line radiation, a band of frequencies including 1420 Mc/s.
2. For observations of the radio continuum, a band in each octave above 30 Mc/s, with a bandwidth of about 2 or 3 per cent.

APPENDIX 3. A STANDARD SEQUENCE OF RADIO SOURCES

This subject was considered by Commission 40 at Dublin in 1955 and a tentative list prepared of radio sources possibly suitable as standards. It was further considered by Commission V of U.R.S.I. at Boulder in 1957. A revised list was drawn up and the revised list submitted to I.A.U. with a recommendation that it should be endorsed by I.A.U. as well as U.R.S.I. Commission 40 supported the U.R.S.I. proposal and the joint recommendation is as follows:

There is now general agreement on the desirability of establishing certain of the stronger discrete sources as members of a standard sequence of flux density. To achieve this objective, U.R.S.I. Commission V and I.A.U. Commission 40:

1. Designate the following sources as members of a standard sequence of flux density:

23N5A (Cas A)	12N1A (Vir A)
19N4A (Cyg A)	16N0A (Her A)
05N2A (Tau A)	09S1A (Hyd A)

2. Call the attention of all radio astronomy observation to the urgent need for more accurate values for the absolute flux densities of the above sources.
3. Recommend that, in observational studies of discrete sources, greater attention be paid to obtaining accurate, well-defined intensity ratios between the objects under observation and the members of the above standard sequence.
4. Recommend that persons making high (pencil-beam) surveys, pay particular attention to the regions surrounding the above sources and publish their findings in the form of detailed maps, perhaps 30 × 30 degrees in area and centred on the individual sources.

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APPENDIX 4. REPORT OF THE SUB-COMMITTEE ON THE PREDICTION OF RADIO SOURCES

History. The predictions of the occultations of discrete sources which have been prepared for some years by H.M. Nautical Almanac Office have been based on the positions of a limited number of sources taken from the Cambridge 2C survey. A greater number of sources with more reliably known positions is now available and H.M. Nautical Almanac Office has sought advice on the most valuable form of future predictions.

Present and contemplated studies. Correspondence with interested radio groups and an informal discussion held on 4 August 1958 at the Paris Symposium have shown the value of continued predictions of occultations, but using revised positions. It will be useful to review continuously the reliability and accuracy of the source positions used in making the predictions as further data become available. It is expected that the observation of occultations will provide two types of information. Further information on the lunar ionosphere will accrue from studies of intense sources, while it is already known that refraction effects are sufficiently small to obtain information about the position of, and intensity distribution across, the majority of the sources.

The several radio groups expect to devote varying amounts of time to occultation work, some being concerned to make only intensive studies of occultations of such particular objects as M 1 and IC 443, while others are preparing to devote an appreciable proportion of observing time with large paraboloids to the study of the fainter sources, or to build special instruments for occultation studies. The latter studies will have the further value of revealing the nature of some outstanding discrepancies between the source surveys at lower intensity levels.

Proposed modifications. In the light of the discussions, the Sub-Committee is at present considering the introduction of the following new procedures in making predictions:

1. To distribute to the radio observatories interested a list of sources for which predictions are made. This will contain all the available radio and optical data for each source and enable the observers to decide what observations might best be made. The list will be kept under constant review.

2. To alter the form of the predictions. Previously these have been in the form of predicted times of occultation for different assumed places of one source. It is now hoped to predict the topocentric place of the Moon at two defined times before and after the occultation of the best available position. This will facilitate the interpretation of the observations.

3. To provide the predictions sufficiently far in advance to enable observers to plan ahead their observing time with large radio telescopes. It is hoped that it will be possible to provide the predictions not less than six months in advance.

In addition to general occultation studies, Mr Seeger calls attention to the desirability of organized programmes of work on occultations of the Crab nebula, depending at each station on the particular circumstances of the occultation. For this radio source more detailed advance predictions will be made available as required.

Future action. The present members of the Sub-Committee are willing to undertake the work outlined above if reappointed in this capacity by Commission 40. It is suggested that (i) new observations of source positions and related queries, (ii) queries relating to the form and the distribution of the predictions, and (iii) particular problems relating to M 1 and IC 443, be communicated respectively to the three individual members of the Sub-Committee:

Dr D. W. Dewhirst, Convenor, Cambridge Observatories.

Mrs F. McBain Sadler, H.M. Nautical Almanac Office, Royal Greenwich Observatory, Herstmonceux.

Mr C. L. Seeger, Sterrewacht, Leiden.

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APPENDIX 5. THE PARIS SYMPOSIUM ON RADIO ASTRONOMY—REPORT BY ORGANIZING COMMITTEE

The I.A.U. Symposium, sponsored jointly with U.R.S.I., was held in the Cité Universitaire, Paris, from 30 July to 6 August 1958. It covered the main fields of radio astronomy of basic interest in astronomy, solar, galactic and extra-galactic; it excluded techniques, meteors and ionospheric effects. It was attended by about 170 participants from at least twelve countries.

The holding of this Symposium was recommended by Commission 40 of I.A.U. in 1955 immediately following the Jodrell Bank Symposium. The organizing committee was as follows: Bracewell (Editor of Proceedings), Denisse (Chairman, French Hospitality Committee), Haddock (Secretary), Hoyle, Lovell, Minkowski, Pawsey (Chairman), van de Hulst, Vitkevitch.

Because of the rapid expansion of radio astronomy and the consequent entry of many new workers into the field it was thought desirable to extend invitations to a considerable number of less experienced workers. With this large attendance it was necessary to restrict the number of scheduled speakers. Different members of the committee took responsibility for the selection of papers and organization of the respective sessions.

The Symposium was very successful. In certain fields, e.g. solar, it brought together diverse observational evidence which fitted immediately into a coherent pattern. In others, e.g. discrete sources in relation to cosmology, the opportunity for discussion of controversial issues greatly clarified perspectives. The Proceedings, including ordinary papers, discussion and introductory and concluding papers to each session, will be published as No. 9 in the I.A.U. Symposia series by the Stanford University Press.

The major difficulty which the organizers encountered in this Symposium was in selecting and restricting the number of scheduled papers so as to allow adequate time for presentation and discussion. With the anticipated growth of radio astronomy this problem will be accentuated in future symposia. It therefore appears that, in future, radio astronomy symposia should be more restricted in scope or a more effective system devised for refereeing or otherwise selecting papers than was available to the organizers of the Paris Symposium. [J.L.P.]