Chapter 3 - Origin of Cosmic Radio Waves.

If our eyes happened to be sensitive to radio waves instead of to light waves then the heavens would take on a completely different appearance. The day time scene would not be dominated by the Sun but by a number of bright "stars" where we had not been accustomed to seeing anything at all. The Sun, a pale shadow of its former self, would be remarkable only for the fact that its brightness occasionally underwent sudden and marked variations. We would not be able to see any of the familiar stars or constellations, although the Milky Way would shine with great intensity. All this is an indication that the radio emission from the heavens generally originates in different processes from those which produce optical radiation.

The earliest observations showed that the radio waves were coming from very localized regions of the skies and suggested a stellar origin, tentatively named radio stars because they did not seem to coincide with any of the bright visible stars. The very first identification however - with the Crab Nebula and several other nebulae which are in fact galaxies well outside our own - tended to verify Jansky's guess that the origin lay in the medium between the stars. Since the Sun is undoubtedly a source of radio waves other stars must also contribute their quota but, because of their remoteness, thiss apparently accounts for only a small fraction of the total. Most of the cosmic radio waves are generated within highly rarefied and usually ionized gas, predominantly hydrogen, by the acceleration of electrons which occurs whenever they are made to change their direction or speed. The residual particles produced when a gas is ionized, i.e. the ions, or in the case of hydrogen protons, are much heavier than the electrons and so are not efficient radiators.

A number of quite separate mechanisms are involved in producing the cosmic radio waves; some of them it is not possible to reproduce in the laboratory. The processes we know of fall into two broad categories; thermal radiation which all bodies emit as a direct outcome of the agitation of the elementary particles of which matter is composed, i.e. of their temperature; and non-thermal radiation which results when electrons are accelerated in other and more energetic ways. The chief sources of the former are solid bodies such as the moon and the planets, and clouds of hot ionized gases which exist in the Sun's atmosphere and in the HII regions* with which the Galaxy is studded. Examples of non-thermal emission are line radiation which is given out at specific frequencies; according to the energy quanta involved, when electrons change from one configuration to another within the atoms to which they belong; synchrotron emission which results when unattached electrons spiral around the lines of force in a magnetic field; and radiation from plasma oscillations, which can take place when the opposing charges within a plasma are momentarily separated and then take up their former positions.

No modulation of any kind has been detected on the celestial radio waves so the only characteristics available for study are their strength or intensity; their spectrum or intensity variation with wavelength (or frequency): and polarization.

The strength of the radiation is usually specified as the flux density (S), i.e. the energy reaching the earth per unit area per second per unit interval of frequency, reference to a frequency interval being necessary because intensity almost invariably varies with frequency wavelength. In m.k.s. units this is expressed in watts per square metre per cycle

*Highly rarefied gases, predominantly hydrogen, exist throughout the Galaxy. Areas where the hydrogen is neutral and optically invisible, astronomers refer to as HI regions; where it is heated and ionized by radiation from a nearby star and so becomes luminous, HII regions.

second ($w.m^{-2}(c/s)^{-1}$). For sources which subtend an appreciable angle and whose emitted flux density varies with position the term brightness is used: this is the flux density from unit solid angle, expressed as watts per square metre per cycle per second per steradian. The flux density S from a source of uniform brightness B which subtends a solid angle of Ω steradeans is then given by $S = B\Omega$.
An alternative way of expressing brightness is in terms of the temperature of a black body which would yeild the observed brightness: this is discussed below.

The cosmic radio waves can be observed over a very wide range, from a few millimetres wavelength, where absorption by water vapour and oxygen begins to be severe, to several hundred metres or so where reflection by the ionosphere prevents the waves reaching the ground. The way in which the flux density received from a source varies with wavelength depends upon the mechanism responsible for the emission and its spectrum is therefore an important characteristic of a source.

The variation of flux density with wavelength is usually expressed in the form

$$S \propto \lambda^{n},$$

n being the flux density spectral index. We shall see below that for purely thermal radiation $S \propto \lambda^{-2}$, i.e. the spectral index is -2. For non thermal radiation of synchrotron origin $n \approx 0.7$.

Some examples of spectra of various kinds are given in Table 2, page .

Thermal Emission

The emission of electromagnetic waves is a basic property of all matter. We are well aware of the light and heat radiated from a body if it is hot enough and that its temperature can be gauged quite accurately by its colour - the principle on which the optical pyrometer is based. However we have no such inbuilt means of detecting electromagnetic waves of the very much longer wavelengths which constitute the radio spectrum, although they are certainly generated by the wide range of motions possible for the individual electrons. In the absence of any specific driving force the electrons vibrate in a random manner, essentially independently of each other. The radiation emitted, therefore, is incoherent, covers all wavelengths without any sharp variations, and is said to be continuous. Magnetic fields play no part in the generation of thermal radio waves so the radiation is not polarized.

The relationship between the temperature of a body and the intensity of the radiation from it at any wavelength can be derived theoretically from the modynamic considerations for "black" bodies, i.e. bodies which absorb all radiation falling on them. This was first given by Planck in a law which bears his name

$$B(f) = \frac{2h\ f^3}{C^2} \quad \frac{1}{e^{hv/KT}-1}$$

where B(f) is the brightness at frequency
h is Planck's constant (6.62×10^{-34} joule-second)
c is the velocity of light
K is Boltzmann's constant (1.38×10^{-23} joule per degree)
T is the absolute temperature of the body (degrees K)
and e is 2.71828.

In deriving this relationship Planck assumed that electrons can radiate energy only in bursts or quanta of amount hf, where h is a constant named after him. At radio frequencies f is small, the quanta are very small, and bodies behave as though the energy were being radiated continuously, instead of in steps. The value of hf is also so much smaller than KT (as long as T is not too close to zero) that Planck's Law can be rewritten with sufficient accuracy as

$$B(f) = 2KT\,\frac{f^2}{c^2}$$

$$= \frac{2KT}{\lambda^2}$$

This was arrived at independently by Rayleigh and Jeans and is known as the Rayleigh-Jeans Law. The way in which the brightness of a black body varies with wavelength is illustrated in Fig. 1: it can be seen to increase rapidly as the wavelength decreases.

Radio sources are not necessarily black bodies, but a convenient way of specifying their brightness at any particular wavelength (or frequency) is in terms of the temperature of the black body which would give the same brightness at that wavelength. This is known as the <u>brightness temperature</u>, or <u>equivalent black body temperature</u>, T_B, and is derived from the relationship

$$B = \frac{2KT_B}{\lambda^2} \quad \text{watts.metres}^{-2}(\text{c/s})^{-1}\ \text{sterad}^{-1}$$

The flux density from an extended source can likewise be expressed in terms of a uniform brightness temperature and the solid angle subtended

$$S = 2.77 \times 10^{-23}\ \frac{T_B}{\lambda^2}\ \Omega\ \text{watts.metres}^{-1}(\text{c/s})^{-1}$$

If a body of uniform temperature is emitting only thermal radio waves, its temperature will, of course, be independent of wavelength and the flux density from it will vary inversely as the square of the wavelength (from the relation $S = 2.77 \times 10^{-3}\ \frac{T_B}{\lambda^2}\ \Omega$), i.e. a source for which

$S \sim \lambda^{-2}$ can be identified at once as emitting only thermal radiation.

The spectral variation of the radio waves from the Moon is identical with that from a black body (see Fig.   ) and identifies their origin as thermal. Its intensity at any wavelength can be used to define the temperature of the level at which the radiation originates, which need not necessarily be the visible surface. Thermal radiation has also been observed from the planets Mercury, Venus, Mars, Jupiter and Saturn: in Jupiter's case non-thermal prosesses are also operating.

Ionized Hydrogen

Clouds of ionised gases which exist in various parts of the Galaxy are a prominent source of thermal radio waves, and they can also absorb radiation from sources which lie behind them. The clouds consist predominantly of hydrogen - the so-called HII regions - which has been ionized by ultra-violet light from a nearby hot star. Electrons and propons are completely separated from each other and in random motion as a consequency of their thermal energy: electrons occasionally approach close enough to protons to be deviated by electrostatic forces (a nominal "collision"), and the resulting acceleration produces emission, the source of energy being the thermal energy of the electrons. The clouds are hot enough to emit the characteristic red light of hydrogen, from which the temperature can be determined: this is about 10000°K for most of the HII regions.

The Orion Nebula (see Plate IV) is an outstanding example of an HII region, just faintly visible with the naked eye but a magnificent sight in a small telescope. The radiation from the gas clouds is effectively spread over all wavelengths without any sharp discontinuities and is said to be continuous.

When an electromagnetic wave enters an ionized plasma the electrons are accelerated by the electric field in the wave (the protons to a negligible extent because of their much greater mass) and if they then undergo collisions with the heavy ions the energy lost in the process will be at the expense of the incident radiation, which will thus suffer some absorption. The absorption coefficient (κ) for a plasma of fully ionized hydrogen is a complicated function of the electron density (N) and the gas temperature T, an approximate value for radio frequencies used in radio astronomy being given by

$$\kappa = \frac{0.1\ N^2}{f\ T^{3/2}}$$

The incident wave will be reduced to e^{-Ks} of its original intensity after travelling a distance s in such an absorbing medium, i.e. it loses a fraction $(1-e^{-Ks})$ in this distance. It can be shown that the brightness temperature of a slab of gas of thickness s is given by

$$T_B = T(1-e^{-Ks})$$

and its brightness is therefore given by

$$B = \frac{2KT}{\lambda^2} (1-e^{-Ks})$$

The quantity $(1-e^{-Ks})$ is known as the "opacity" of the slab of plasma: the brightness temperature of the slab of gas is thus the product of its temperature and its opacity.

When Ks has a value considerably greater than unity, i.e. when the cloud is opaque, the expression within the bracket becomes unity and so $T_B = T$ 10,000°K. The gas therefore emits as a black body at that temperature. This happens at the longer wavelengths, above about 3 metres. At high radio frequencies however Ks is much less than unity, so

$$B = \frac{2KT_{Ks}}{2} = \frac{0.2 K N^2 s}{C^2 T^{\frac{1}{2}}}$$

i.e. the brightness is independent of wavelength. The opacity falls off rapidly for wavelengths shorter than about 3 metres. The spectral index for thermal radiation from HII regions thus changes from an index of -2 (corresponding to black body radiation) at long wavelengths to an index of 0 as the wavelength becomes shorter (see Fig.).

HII regions are relatively prominent sources of radio emission at short wavelengths but stand out as dark clouds at long wavelengths because they absorb the higher temperature background radiation coming from regions behind them.

The brightness of radio sources which lie behind semitransparent clouds is modified by these absorbing screens. Suppose an emitting region of true brightness is T_s is observed to have a brightness T_a when observed through an absorbing medium of equivalent temperature T_m. Then the flux received at the ground will be the sum of that which passes through the medium plus that radiated by the medium itself.

It was shown above that the brightness temperature of a slab of gas is given by the product of its temperature (T_m) and the fraction of the incident wave which is absorbed

Thus $T_a = T_s\, e^{-\kappa s} + T_m\, (1-e^{-\kappa s})$

Hence if the brightness temperature of the background region is the same as that of the absorbing cloud, i.e. if $T_m = T_s$, then $T_a = T_s$ and there will be no indication of the presence of the cloud. If however the background brightness is greater than that of the medium the cloud will appear less bright, i.e. it will appear darker in absorption. Conversely if the temperature of the absorbing cloud is the higher, then the observed brightness will be higher than that of the background and the cloud will appear bright in emission.

Non-Thermal Emission

Radiation which is the result of other than thermal processes is characterised by a recognizably different spectrum. The chief processes responsible for non-thermal radiation from extra terrestrial are as follows:

1. Line Emission

Light waves originate mostly from atomic or molecular processes and hence tend to occur at discrete frequencies, whose presence or absence in the light from a star has provided the basis upon which virtually all our knowledge of the physical conditions on celestial bodies had been based before the advent of radio astronomy. Cosmic radio waves, for the most part, arise from processes which result in more or less continuous emission, and until 1951 all radio astonomy observations were carried out in this "continuum". As early as 1945 van der Hulst had predicted that radio frequency emission at a wavelength near 21 cms showed result from a "hyperfine" transition which is possible for the single electron of the hydrogen atom and that this emission should be detectable. This prediction was reinforced as the result of an independent analysis by Shklovsky in 1949, but it was not until 1951 that such emission was first observed by Ewen and Purcell at Harvard. Their results were confirmed within a matter of weeks by Christiansen and Hindman in Sydney and by Muller and Oort in the Netherlands.

The "hydrogen line" has proved to be one of the most important discoveries of radio astronomy because the emission results from cold neutral hydrogen which is completely invisible by optical means. Its study has provided a powerful means for investigating the structure of our Galaxy, and of other galaxies, and for studying the properties of the gas that lies between them (see Chapter).

Discovery of the hydrogen line stimulated a search for other lines in the radio frequency spectrum, the first to be attempted being the analogous line from deuterium, which should occur at a wavelength of about 92 cm (327.38 MHz). A careful search by a number of observers has, however, so far failed to detect this emission, and likewise radio frequency emission from atoms such as carbon, silicon etc. which are known, from optical observations, to be abundant in stellar atmospheres. No further lines were found until 1963 when absorption observed at a wavelength of about 18cm in the direction of the Galactic Centre was first ascribed to an unknown element "mysterium" and turned out to be due to the hydroxyl radical O.H. (see chapter). Discovery of the existence of OH in the galaxy came as a great surprise: further observations suggest very strongly that it is associated with the early stages of star formation, and the O.H. emission thus provides a means for locating protostars. The fact that conditions favourable for the formation of O.H. obviously exist within the Galaxy prompted the search for other molecules and in 1968 a team at the University of California, Berkeley, was successful in detecting weak emission from ammonia, NH_3, at a wavelength near 1.25 cms from a dense cloud of gas and dust (also a source of OH) which lies in the direction of the galactic centre. Not long after this the same group reported detection of the presence of water, H_2O, in interstellar regions by means of microwave emission at a wavelength near 1.3 cms which comes from a rotational transition in the water molecule. Emission was observed from the same cloud which was found to contain ammonia, and from several other regions, including the Orion Nebula. The most recent and most surprising discovery of all (1969) is that of a group at the American National Radio Astronomy Group at Greenbank, West Virginia, who have detected relatively strong emission from famaldehyde, at a wavelength near 6 cms, in a number of the regions of dust and gas which have been found to contain OH, NH_3 and water. These remarkable discoveries are dealt with more fully in Chapter .

Transitions of orbital electrons between energy levels of very high principal quantum number can also result in radio frequency emission. This was first detected in the U.S.S.R. by Dravskikh et al. in 1964, the transition involved being between levels of quantum number 105 and 104 for the hydrogen atom. (This line has been designated as 104α, the convention being that the subscript α denotes transitions between levels differing in quantum number by 1, β for levels differing by 2, etc.) Many such recombination lines have since been discovered involving the hydrogen atom and several for the helium atom: they are invariably observed in sources associated with HII regions and indicate that the gas is in a highly ionised state.

Synchrotron Radiation

Radiation to which this name has been given was first observed as a glow of blue light in the General Electric Company's synchrotron, completed just after Word War II: it was explained by Schwinger (1949) as a natural consequence of the acceleration undergone by the high-energy electrons as they followed spiral paths, with speeds approaching that of light, around the lines of force of the strong magnetic field within the synchrotron. Alfrien and Herlofson in Sweden were the first to suggest (1950) that synchrotron radiation may be the source of emission from the discrete radio sources: in the weaker fields to be expected the emission would be shifted to longer wavelengths, i.e. to the radio spectrum. Shortly afterwards Kiefenheuer explained the background of radio emission from the Galaxy as originating in this way, and suggested that cosmic rays provide the source of the electrons. Later, U.S.S.R. theoretician Shklovsky suggested that not only the radio waves but also the light from the well known radio source the Crab Nebula should originate in this manner. The subsequent observation of polarization of both optical and radio emission from the Crab led to the general acceptance of this mechanism as a basic source of cosmic non-thermal radio waves.

The theory of the synchrotron process is complex, but a simplified description is as follows. A low-energy particle moving at right angles to a magnetic field is constrained to describe a circular path at a frequency which is determined by the strength of the magnetic field and the ratio of change-to-mass of the particle. Radiation is emitted or absorbed at this frequency, which is known as the <u>gyro frequency</u>: for electrons in the earth's ionosphere this is approximately 1.4 MHz. In the very much smaller fields existing within the spiral arms of the galaxy ($\sim 10^{-5}$ gauss) the natural gyro frequency for low energy electrons would be only 20-30 hertz. For electrons of higher energy and consequently moving at higher speeds the relativistic increases in mass result in the emission of harmonics of the gyro frequency, which as the speed approaches that of light, cover the whole radio range. The resultant emission is effectively continuous but has a maximum at a frequency which is dependent upon the total energy of the electrons: for electrons of energy 10^9 electron volts, for example, maximum emission occurs at about 60 mc/s (wavelength of 5 metres). This radiati is concentrated in a narrow core centred on the instantaneous direction of motion of the electrons, and a characteristic feature is that it is polarized in a plane which is perpendicular to the component of magnetic field at right angles to the line of sight.

The spectrum of the emission from a cloud of relativistic electrons within a radio source will depend upon the energy distribution of the electrons themselves. If the energy spectrum is of the form N = constant x $E^{-\alpha}$ where N is the number of electrons with energy E and α is the energy spectral index, then it can be shown that the brightness or flux density of the radio source will be proportional to $\lambda^{(\alpha-1)/2}$. If the source of electrons is cosmic rays for which α is 2.4, then for a radio source emitting by the synchrotron process the flux density will be

$$S = \text{constant} \times \lambda^{0.7}.$$

Observations show that apart from the Sun and the gaseous nebulae or HII regions, the spectra of both galactic and extragalactic sources are similar and closely approximate that of synchrotron radiation (see Fig.). There is little doubt that this is a basic source of non-thermal cosmic radio waves.

Cerenkov Radiation

When high-energy particles penetrate a medium in which the velocity of light is smaller than their own, electromagnetic waves are mdiated along a conical surface centred on their direction of rotation. This mechanism may account for some of the radio emission from the dense plasma constituting the solar corona.

Plasma Oscillations

A completely different type of non-thermal radiation is possible from a plasma or completely ionized gas as a result of the natural oscillations which occur if the positive and negative changes are displaced and then released. In the case of the Sun the excitation is produced by streams of charged particles moving outwards in the solar atmosphere. Oscillations are excited at the natural plasma frequency (which is determined by the electron density) and as the electron density in the solar corona decreases with height, this results in bursts of emission at successive levels, whose frequency decreases progressively with time (see Chapter). A characteristic of plasma oscillations is substantial radiation also at the harmonic frequency, and direct observation of this in connection with solar bursts of particular types has confirmed the plasma oscillations as the causative mechanism.

Plasma oscillations have not been observed in any other radio sources than the Sun. It is possible, however, that they may be responsible for the short duration bursts which have been observed from flare stars.

Effects of the Terrestrial Atmosphere

The wavelengths used in radioastronomy are large in relation to the dimensions of the particles in the atmosphere which are responsible for haze, cloud and rain, and so radioastronomers are virtually immune from interruptions to their observing schedules due to weather. In the passage of the waves through the full depth of the terrestrial atmosphere, however, some deviation and absorption occurs.

The lower atmosphere is virtually transparent to the longer radio wavelengths but the shorter waves may be attenuated as the result of simple Rayleigh scattering ($\propto \lambda^{-4}$) due to liquid water droplets in clouds, or by absorption due to water vapour oxygen. Attenuation by cloud is seldom appreciable at wavelengths longer than about 10 cms. Absorption by atmospheric gases becomes appreciable at wavelengths in the vicinity of the water vapour absorption line which occurs at 1.2 cms and near 0.5 cms due to absorption by oxygen (see Figure 3).

The longer wavelengths are subject to absorption within the ionosphere, particularly the F_2 layer, the amount depending on the critical frequency of the layer in relation to the observing frequency. A further source of attenuation is the severe absorption within the D layer which occurs during radio fadeouts, i.e. following major solar flares. The lower limit for useful radio astronomy observations is thus about 300 metres (1 MHz) and the upper limit about 1 cm (30 GHz). Apart from the effects mentioned above the intensity of the incoming waves may also be varied if atmospheric conditions are such as to cause either convergence or divergence of the waves.

Refraction effects are also present both in the lower atmosphere and within the ionosphere. Due to the high refractivity of water the deviation of radio waves may be about double that of light waves in the lower atmosphere, a typical value being 0.5^{o} at 1^{o} true elevation. The deviation produced within the ionosphere becomes appreciable at the longer wavelengths a typical value for a wavelength of 5 metres (60 MHz) being 20 minutes of arc at a true elevation of 3^{o}. Knowledge of the refraction effects is particularly important when the precise position of sources is being determined.

The intensity of the incoming radio waves often undergoes marked fluctuations with periods of up to a minute or so. This has been shown to be due to moving irregularities in the ionosphere and is thus analogous to the twinkling of visible stars. Other shorter period fluctuations known as "scintillations" are commonly observed when so-called point sources are within a few degrees of the Sun, the effect in this case being due to varying diffraction as the waves pass through streams of hot plasma being ejected from the Sun.

Effect of Magnetic Field

The generation and propagation of radio waves in an ionized medium pervaded by a magnetic field such as the terrestrial ionosphere is covered by the magneto-ionic theory as developed by Lorentz and Appleton and will not be discussed here.

An essential characteristic of synchrotron radiation is that is shows some polarization; the first observation of such polarization was made in 1962 by Mayer et al. in the U.S.A. Shortly afterwards, following the completion of the Australian 210 ft. radio telescope at Parkes, came the discovery by Cooper, Gardner and their associates of Faraday rotation in the radio waves from several sources, and the demonstration that large-scale magnetic fields exist in interstellar space. When radio waves which are polarized pass through a medium containing electrons and a magnetic field, then the direction of the plane of polarization is rotated by an amount which depends on the strength and orientation of the field, the electron density, the length of path and the observing frequency. This is known as the Faraday effect. The rotation waves inversely as the square of the frequency so that from observations at a number of frequencies it is possible to derive the direction of polarization which would be observed at an infinite frequency, i.e. the direction of polarization, and hence of the magnetic field, at the source. Fig. 4.

Faraday rotation also occurs in the Earth's atmosphere but the effects observed in the signals from the source Centaurus A (the nebula NGC 5128) are much too great - and do not vary with time of day - to be attributed to the ionosphere. They indicate clearly the existence of a large scale magnetic field over a large volume of interstellar space: theoreticians had found it necessary to postulate the existence of such fields, to account, for example, for the origin of cosmic rays and to explain the majestic structure of spiral galaxies. The first demonstration of the existence of such fields, however, came from the radioastronomers. A series of observations, mainly by Garduer, Whiteoak, Cooper and their associates in Australia, on a large number of sources show that most of the Faraday rotation takes place within our own Galaxy. These observations thus enable the Galactic magnetic field to be plotted (see Chapter) and reveal its concentration in the spiral arms.

Frequency Allocations for Radio Astronomy

The cosmic "signals" with which radio astronomers are concerned are, in general, at a level orders of magnitude below those dealt with in ordinary radio communication practice, and they are entirely noise-like in character, i.e. they carry no modulation which would serve to distinguish them from interfering signals. Further, receivers used are several orders of magnitude more sensitive than those in commercial practice, this additional sensitivity often being achieved by the use of very wide bandwidths which render them very susceptible to interference. The fundamental measurement in radio astronomy, that of the power output from the receiver due to the source being observed, is thus impossible to make in the presence of appreciable signal levels from terrestrial transmissions or sources of interference. The measurements are also subject to errors which may be serious if made in the presence of interference which is at a level so low as to escape recognition. Freedom from interference from man made transmissions is thus vital and becoming increasingly so as radio astronomers reach even further into remote areas of the cosmos.

The task of allocating frequencies among the various communication services and other users of the radio spectrum - and also of giving protection to authorised services from unauthorised transmissions - is carried out by the International Telecommunications Union, one of the specialized agencies of the United Nations. The special needs of radioastronomy and of space science in general were considered at an Extraordinary Administrative Radio Conference held in Geneva in 1963 and received what can be regarded as substantial recognition, bearing in mind the fact that commercial or military services of long standing were already established in most of the wavelength bands of interest to radioastronomers. The final outcome of the Conference was allocation to the radioastronomy service of 20 separate bands within the range 2.5 to 40 mc/s. These are set out in Appendix . The majority of them, however, are shared with services which operate transmitters, but several offer ideal protection in the form of an exclusive allocation to radioastronomy throughout the world. The most useful of these is a wide band from 1400-1427 mc/s for observation of the hydrogen line, the other exclusive allocations being at 2700, 10.7, 15.4, 19.4 and 31.5 mc/s. The main deficiencies are adequate bands at the longer wavelengths, where the spectrum is heavily occupied with commercial services, and radio astronomy observations can only be made at limited times. The international scientific Unions interested in radio astronomy (the International Astronomical Union (IAU) and the International Scientific Radio Union (U.R.S.I.)) are continuing to press for improved conditions throughout the spectrum and there is hope that this will in due course be achieved.