PART III

GALACTIC STRUCTURE AND STATISTICAL STUDIES OF POINT SOURCES

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PAPER 37

GALACTIC RADIO EMISSION AND THE DISTRIBUTION OF DISCRETE SOURCES

INTRODUCTORY LECTURE BY

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At wave-lengths greater than about 1 metre the majority of the radio emission which is observed from the Galaxy cannot be explained in terms of thermal emission from ionized interstellar gas. This conclusion is widely accepted and is based on observations of the equivalent temperature of the sky and the spectrum of the radiation. The spectrum at metre wave-lengths is of the general form:

$$T_A \propto \lambda^n$$

where T_A is the equivalent black-body temperature of a region of sky and λ is the wave-length. The exponent n varies with direction but lies between about 2·5 and 2·8, and is thus significantly greater than the value of 2·0 which is the maximum to be expected for thermal emission from an ionized gas. Furthermore, the value of T_A is about 10^{5}° K. at 15 metres and thus greatly exceeds the electron temperature expected in H II regions.

At centimetre wave-lengths it is likely that the majority of the radiation observed originates in thermal emission from ionized gas; however, the present discussion is limited to a range of wave-lengths from about 1 to 10 metres where the ionized gas in the Galaxy is believed to be substantially transparent and where the origin of most of the radiation is believed to be non-thermal.

I. SOME FEATURES OF THE GALAXY AT METRE WAVE-LENGTHS

(*a*) *The general background radiation*

Early surveys [1, 2, 3, 4, 5] of the sky showed that the general radiation is, broadly speaking, concentrated in latitude about the galactic plane and in longitude about the galactic centre. On the basis of these surveys, it was concluded [6] that the sources of emission in the Galaxy, whatever they may be, have a space distribution like that of the common stars. Irregularities in the distribution, which are increasingly pronounced as the wave-length is decreased, were attributed to the effects of spiral structure in the Galaxy.

The early surveys were made with rather wide beams and it is now known that much important detail was lost. Thus a recent high resolution survey by Scheuer and Ryle [7] and also some unpublished work by Mills suggest that the true distribution of intensity normal to the galactic plane is made up of perhaps three component distributions. Two of these components are narrow and have widths of about 2 and 10°. It is difficult, without more extensive surveys, to be sure of their independent existence and this is a problem which requires a considerable amount of further study. The third component appears to be much broader and to have a width of the order of 120°. The variation of these components with galactic longitude is not yet known satisfactorily and is clearly complicated by irregularities in galactic structure; nevertheless it is known that the narrow distributions show a marked concentration towards the galactic centre, while the broader component appears to be concentrated to a lesser extent in that direction.

The space-distribution of the sources of the broad component presents a particularly interesting question, and it is difficult to escape the conclusion that the Galaxy has a radio corona which extends to great distances. In the earlier interpretations of the isophotes it was found that agreement with the general distribution of mass in the Galaxy could be obtained by assuming that a large fraction, about two-thirds, of the total radiation was isotropic and probably of extra-galactic origin. It seems likely, as has been suggested by Shklovsky [8], that a substantial fraction of this isotropic component must now be attributed to the Galaxy and associated with the broad distribution.

(*b*) *The discrete sources at metre wave-lengths*

The first surveys of the discrete sources, or radio stars, were made with interferometers and its was concluded from these results that the distribution of sources with direction from the sun is isotropic [9]. While this is still believed to be true of the majority of sources, it is now recognized that the resolving power of the interferometers was so high that important sources of large angular diameter were missed. It appears that there are at least two classes of source.

Class I sources, which form a minority of the total, are of relatively high intensity and show a pronounced concentration into the galactic plane [10, 11].

A surprising feature of these sources is that many of them are known to have apparent angular diameters greater than one degree [12].

Class II sources, which form the majority, appear to be uniformly distributed over the sky. The angular diameters of many of these sources are not yet known and it is important that they should be measured; however, the few results which are available suggest that, for the most part, their diameters are of the order of a few minutes of arc or less.

2. THE ORIGIN OF THE RADIO EMISSION FROM THE GALAXY AT METRE WAVE-LENGTHS

Any discussion of the origin of the radiation from the Galaxy must be highly speculative, since recent work has shown that our knowledge of the distribution of the background radiation is seriously incomplete. Furthermore, data on the spectra and angular diameters of the sources are confined to a few of the most intense.

The present evidence suggests that any theory may have to account for both the broad and narrow distributions although it is by no means clear whether these distributions can be regarded as independent.

Two components of the narrow distributions are the thermal radiation from ionized gas in H II regions and Class I sources. At metre wave-lengths the thermal radiation cannot account for the total intensity observed and it is tempting to ascribe the remainder to a population of sources which lie close to the galactic plane. However, this cannot be done, since so little is known about the Class I sources; for example it is not known whether they are a homogeneous population, nor how they are distributed in the Galaxy. Until more data are available we must be prepared to find that some other mechanism, as yet unknown, is responsible for the majority of the radiation. For example, it has been suggested [13, 14, 15, 16, 17] that the non-thermal radiation might be due to cosmic-ray electrons in interstellar magnetic fields.

The nature of the known Class I sources is a fascinating problem. They appear to be rare bodies with a space-density in the neighbourhood of the sun, which we may compare, solely for the purpose of illustration, with that of planetary nebulae. The spectra and apparent surface temperatures of a few of these sources are known and it is clear that some of them are radiating by a non-thermal mechanism. The large angular diameters of several of these sources [12], coupled with the few photographic identifications which have been made [12, 18, 19, 20], suggest that they are associated with extended nebulosities. These nebulosities are of low photographic brightness and some of them have been found to contain filaments which are apparently moving at very high speeds. The nature of these nebulosities is controversial. At least two, if not three, of the sources have been identified with the remnants of supernovae [21, 22, 23], and it has been suggested [24, 25] that many of the other sources arise in the same way.

The physical mechanism by which these nebulosities radiate is also unknown. It seems likely that plasma oscillations cannot be invoked since the plasma frequency in the medium is too low, and the current idea is that the radiation arises from the deflexion of relativistic electrons in magnetic fields [26]. The magnetic fields are presumed to be generated by turbulence in an ionized medium, and the fast electrons to be accelerated by the Fermi mechanism, by shock waves, or by some other process.

The origin of the broad distribution is also a challenging problem and it is an urgent task of observation to establish beyond doubt the shape and spectrum of this distribution. It has been suggested [8, 27] that, whereas the narrow distributions are apparently associated with populations concentrated into the galactic plane, the broad distribution arises in an extended halo which is roughly spherical and extends to radial distances of the order of 10,000 parsecs. It has also been proposed that the generation of the energy in this halo occurs in a very rarefied medium and is due to the deflexion of fast electrons in magnetic fields.

The origin of the majority of the discrete sources, the Class II sources, may be extragalactic. Recent work [23] has shown that their distribution is remarkably isotropic and it is difficult to associate them with any of those components of the background radiation which are clearly of galactic origin.

3. EXTRAGALACTIC SOURCES

A small number of radio sources have been identified with external galaxies, and on the basis of these results it appears that, as far as radio emission is concerned, we must recognize at least two major classes of galaxy, *normal* galaxies and *peculiar* galaxies [28].

(a) *Normal galaxies*

A study of six type-Sb galaxies shows that they radiate roughly the same ratio of radio to light flux [29, 30]. If the intensity of radio emission at the earth is I w.m.$^{-2}$ (c./s.)$^{-1}$ then, at a wave-length of about 1·9 metres, it has been found that the photographic and radio magnitudes may be taken as roughly equal if we define the radio magnitude (m_R) by the equation:

$$m_R = -53{\cdot}4 - 2{\cdot}5 \log I.$$

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It is clearly of great interest to know how the value of $m_R - m_{pg}$ varies with the type of galaxy and this is one of the major observational problems of radio astronomy. At the present moment the available evidence is insufficient to draw any definite conclusions about this question.

(*b*) *Peculiar galaxies*

A few radio sources have been identified with peculiar objects of which the best known is the pair of colliding galaxies in Cygnus [18]. These are to be described later in greater detail by Dr Minkowski and so will not be discussed here.

(*c*) *Our own Galaxy*

A comparison of the radio emission and the light from M31 suggests that, as far as radio emission is concerned, it behaves as a normal Sb galaxy [29]. Furthermore a comparison of our own Galaxy with M31 indicates that the two systems are similar in respect to their total radiation at metre wave-lengths. Thus the total radiation from our Galaxy [31] at 1·9 metres is of the order of $5{\cdot}0 \times 10^{20}$ watts $(\text{c./s.})^{-1}$ steradian^{-1}, which is in close agreement with that found for M31. In conclusion the extended distribution of radiation around M31, which has been reported by Baldwin, suggests that both our own Galaxy and M31 may possess large radio coronas.

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Discussion

Ryle: The interferometric measurements by Scheuer [1] of the distribution of intensity at low galactic latitudes had sufficient resolving power to give the true latitude distribution without effects associated with 'aerial smoothing'. The curves obtained show with absolute certainty the presence of the two components; a narrow belt having a width to half-intensity of the order of $\pm 1^{\circ}.2$, and the 'second component' which for longitudes between 345° and 30° falls to half-intensity at about $\pm 10^{\circ}$.

Steinberg: Our observations at 33 cm. also clearly show the presence of a narrow component and a much broader one.

Westerhout: Another proof of the existence of a corona around the galactic system may possibly be obtained from 21-cm. line observations. Recent observations at Kootwijk show the presence of very long wings to line profiles at high galactic latitudes. Neutral hydrogen with a very small density and high velocities thus seems to be present at large distances from the galactic plane.

Burbidge: A possible explanation of the origin of the halo, corona, or aura, of radio emission observed in M31 and in our Galaxy by Mr Baldwin may be obtained by extending the ideas of Pikelner, Shklovsky and Ginzburg who first suggested that there is an extended distribution of gas and magnetic field extending normal to the spiral planes. By using the conditions for the emission of synchrotron radiation by relativistic electrons, for the stability of the spheres of diffuse gas (with radii of the order of 10–15 kiloparsecs), and for the energy density of the electrons to be much less than the cosmic-ray energy density in the planes, I have concluded [2] that the most plausible values of the parameters are

$\overline{H} \approx 10^{-6}$ gauss,
ρ (mean density in the diffuse spheres) $\approx 10^{-26} - 10^{-27}$ g./cm.^{3},
v (turbulent gas velocities) ≈ 200 km./sec.,
E (electron energies) $\approx 2 \times 10^{9}$ eV.

A fairly uniform distribution of radio brightness away from the planes is obtained since the electrons lose energy by radiation but continuously gain it by collisions with turbulent magnetic cloud elements (Fermi mechanism) whose 'cores' must be about 100 parsecs apart.

The origin of the high-energy electrons is rather uncertain. I have considered that pair production in collisions between high-energy protons of cosmic radiation and thermal photons may be important. Another possibility is that electrons will be the end products following meson decay after the mesons have been produced in high-energy nucleon-nucleon collisions.

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