GALACTIC NONTHERMAL RADIATION. DISTRIBUTION OF SNRs AND PULSARS

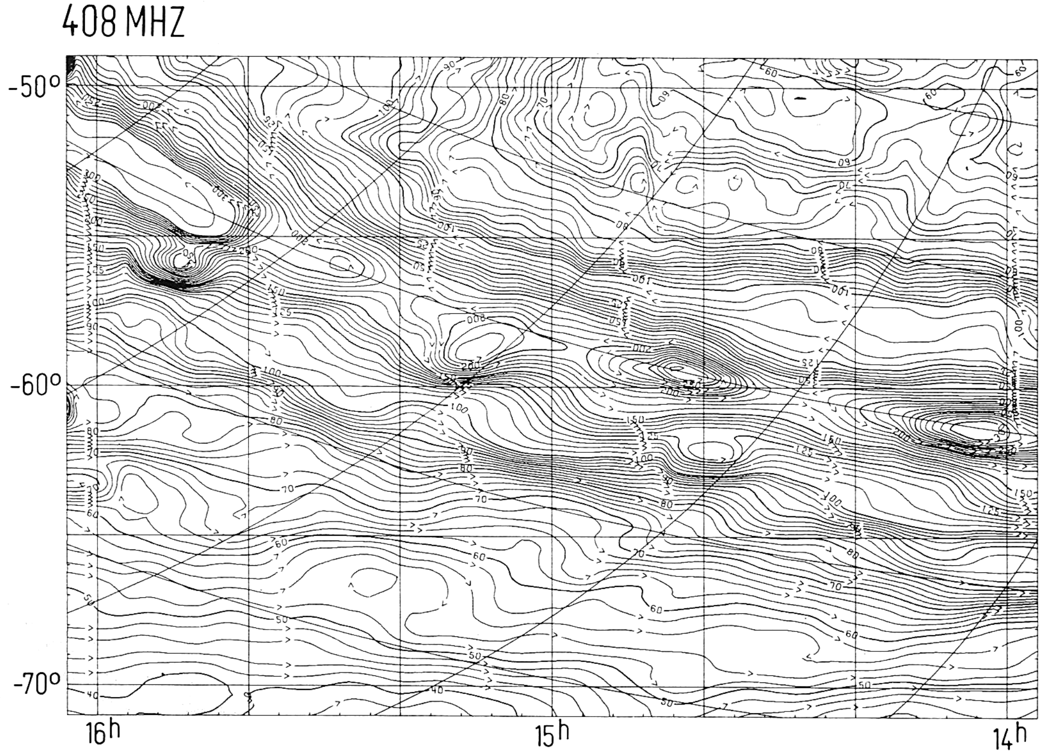
R. Wielebinski
Max-Planck-Institut für Radioastronomie, Bonn, F.R.G.

All sky surveys of the radio continuum emission give us the basic information on the distribution of the nonthermal emission in the Galaxy. At metre wavelengths, where nonthermal emission is dominant, good angular resolution is difficult to attain. For many years the best surveys near 2 m wavelength gave us a picture of the galaxy with $\sim 2^{\circ}$ resolution. At centimetre wavelengths, where arc min resolution is available, the intense HII regions dominate the radio sky. Supernova remnants have a distribution somewhat similar to that of the discrete HII regions and must be delineated by various methods in high resolution galactic plane surveys in the decimetre wavelength range.

Surveys which cover a substantial part of the sky are available currently for frequencies as low as 1 MHz and as high as 820 MHz. A tabulation of the major all sky survevs is made in Table 1. Below 10 MHz, with a few exceptions, satellites (e.g. Novaco and Brown, 1978) have been used. It should be noted that in the surveys with good angular resolution below 30 MHz parts of the galactic plane are seen in absorption. The only combination survey which covers all the sky with a resolution of $\sim 2\overset{\circ}{.}2$ is still the 150 MHz map of Landecker and Wielebinski (1970). A series of observations made in Jodrell Bank, Effelsberg and Parkes by Haslam et al. (1970, 1974, 1975) have covered nearly all the sky at 408 MHz with a resolution better than 1°. To complete the survey the north polar cap will be surveyed in Jodrell Bank soon. These surveys should in future be the basic starting point for interpretations of the galactic nonthermal emission. There is a sad lack of good quality sky surveys at frequencies above 1 GHz. This is due to the fact that nonthermal emission falls to average values below 1 K at 1420 MHz and to less than 0.1 K at 2695 MHz in 'cold' regions. A survey of the northern sky at 1420 MHz with r.m.s. noise of $\sim$ 15 mK is at present in final stages of reduction (Reich, 1977).

Any survey with good temperature and angular resolution shows a great amount of detailed structure. As an example a section of the 408 MHz survey is shown in Figure 1. At high galactic latitudes extragalactic point sources stand out. Nearer to the disc numerous spurs

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 113–118.



are seen. These have been interpreted to be nearby supernova remnants (e.g. Berkhuijsen, 1973). Recently an alternative explanation, in which the North Polar Spur is interpreted to be due to magnetohydrodynamic waves from the galactic centre, has been put forward by Sofue (1977). Still nearer the galactic plane the intensity of emission rises rapidly. Three dominant features are Cygnus X, the galactic centre, and Vela X. From the symmetry of Cygnus X and Vela X complexes their interpretation as tangential directions of our spiral arm (or interarm) seems to be definitive. Other 'steps' due to the inner spiral arms can also be seen, particularly in the southern maps, and especially somewhat away from $b = 0$. Inside the area $60^\circ < \ell < 300^\circ$ and $b = \pm 5^\circ$ a complicated mixture of thermal and nonthermal emission is observed. A tabulation of the major galactic plane surveys is given in Table 2.

The need for good surveys of a broad strip of the galactic plane at numerous frequencies is dictated by the wish of separation of the thermal component in the total radiation. There is some evidence that in addition to the discrete HII regions diffuse thermal emission is present in the Galaxy. This may be a superposition of separate HII regions or diffuse clouds which escaped from the ionised shells. The separation of thermal emission from the nonthermal component, although quite simple in theory, is hampered by numerous instrumental problems. The determination of the base levels and the adjustment of a survey to

TABLE 1
SELECTED SURVEYS OF ALL SKY

FREQUENCY (MHZ)	BEAM (DEGREES)	COVERAGE	REFERENCE
1.3, 2.2, 3.9, 4.7, 6.6, 9.2	120-45	NEARLY WHOLE SKY	NOVACO, J.C., BROWN, L.W. 1978, AP. J. 221, 114
2.1	7.1	$0^H < \alpha < 24^H$, $\delta < 0^0$	REBER, G. 1968, J. FRANKL INST. 285, 1
10.0	2.0	α INCOMPLETE, $\delta > -5^0$	CASWELL, J.L. 1976, MNRAS 177, 601
150	2.2	ALL SKY	LANDECKER, T.L., WIELEBINSKI, R. 1970, AUST. J. PHYS. AP. SUPPL. 16, 1
408	0.75	$4^H < \alpha < 12^H$, $60^0 > \delta > -20^0$ $0^H < \alpha < 04^H$, $60^0 > \delta > 20^0$	HASLAM ET AL. 1970, MNRAS 147, 405
408	0.6	$12^H < \alpha < 04^H$, $48^0 > \delta > -8^0$	HASLAM ET AL. 1974, A & A SUPPL. 13, 359
408	0.85	$0^H < \alpha < 24^H$, $0^0 > \delta > -90^0$	HASLAM ET AL. 1978 (IN PREPARATION)
820	1.2	$0^H < \alpha < 24^H$, $85^0 > \delta > -7^0$	BERKHUIJSEN, E.M. 1972, A & A SUPPL. 5, 263
1420	0.5	$0^H < \alpha < 24^H$, $90^0 > \delta > -19^0$	REICH ET AL. 1978 (IN PREPARATION)

TABLE 2
SELECTED GALACTIC PLANE SURVEYS

FREQUENCY (MHZ)	BEAM (MIN)	COVERAGE	REFERENCE
29.9	48	$30^0 < \ell < 225^0$ $b \pm 10^0(15^0)$	JONES, B.B., FINLAY, E.A. 1974, AUST. J. PHYS. 27, 687
408	3	$55^0 < \ell < 195^0$ $b \pm 3^0$	GREEN, A.J. 1974, A & A SUPPL. 18, 267
1410	14	$356^0 < \ell < 281^0$ $b \pm 5^0$ (6^0)	HILL, E.R. 1968, AUST. J. PHYS. 21, 735
1414	10	$55^0 < \ell < 12^0$ $b \pm 4^0$	ALTENHOFF ET AL. 1970, A & A SUPPL. 1, 319
2695	8	$47^0 < \ell < 286^0$ $b \pm 2^0$	DAY ET AL. 1969-70, AUST J. PHYS. SUPPL. 11, 13
2695	11	$75^0 < \ell < 345^0$ $b \pm 2^0$	ALTENHOFF ET AL. 1970, A & A SUPPL. 1, 319
4875	2.6	$60^0 < \ell < 357\overset{\circ}{.}5$ $b \pm 1^0$	ALTENHOFF ET AL. 1978, A & A SUPPL. (IN PRESS)
5000	4.1	$40^0 < \ell < 190^0$ $b \pm 2^0$	HAYNES, R.F. 1978, AUST. J. PHYS. (IN PRESS)

an absolute temperature scale are only now reaching a stage of accuracy where a meaningful separation may be possible. Furthermore, the degree of linear polarisation of the nonthermal component above 1 GHz is high, possibly up to 75% in some regions (e.g. Brouw and Spoelstra, 1976). The linearly polarised component is pure nonthermal emission. It seems that in order to obtain a definitive separation surveys which contain complete polarisation information at a number of high radio frequencies may be necessary. Although difficult in execution, this is a very important venture, which should be carried out in the next years to further our understanding of the emission processes in the Galaxy.

The intensity contours determined in a sky survey are a superposition of the following components:

1. Extragalactic background
2. Galactic disc emission (HII regions, SNRs, spiral arms)
3. Local emission (Spurs, Cygnus X, Vela X)
4. Remaining "halo" emission.

Components 1-3 may be determined each with a certain degree of reliability. In particular it is difficult to separate the numerous spurs. The subtraction of these three components from a reliable sky survey gives finally the intensity of the remaining emission, of a halo. The halo is of great importance in high energy astrophysics, since confinement (or otherwise) of cosmic rays in the Galaxy can best be tested by observing the nature of any radio halo surrounding our Galaxy (e.g. Ginzburg and Ptuskin, 1976; Ginzburg, 1977 and references therein). Original sky survey results indeed supported the existence of an electron halo. Refined measuring techniques, particularly sidelobe determinations, have gradually reduced the intensity which could be attributed to the halo (e.g. Baldwin, 1967, 1976). Alternative experiments to test the halo hypothesis have been conducted by numerous observers (e.g. Wielebinski and Peterson, 1968) and placed low upper limits on a halo component. Finally a detailed analysis by Webster (1975), using different observing techniques, implied the existence of a weak, nonconfining halo. All the evidence available from direct interpretation of sky surveys points to a weak halo. An alternative approach to this problem is to compute three-dimensional models of the radio emissivity. A number of papers (Brindle et al., 1978 and references therein) use all the available evidence on the magnetic fields, the density wave theory and energy distribution of cosmic rays to produce 'maps' which can then be compared with existing surveys. The best fit is obtained for a model with a thick disc. The increase in spectral index away from the plane of a galaxy which seems to be now definitively documented has not as yet been considered in any such models. A good discussion of the problems associated with modelling is found in Baldwin (1976). Additional evidence which supports the above conclusion comes from the analysis of γ-ray observations. Stecker and Jones (1977) show that the data can best be explained by an electron halo with a half thickness $L_e = 2 \pm 2$ kpc. Observations of nearby edge-on galaxies also support such a model. The galaxy NGC 4631 has the most distinctive ellipsoidal halo at 610 MHz (Ekers and Sancisi, 1977). The edge-on galaxy NGC 891 also shows a rather weak halo which has a steep spectrum away from the plane of this galaxy (Allen et al., 1978). The increase in the spectral index away from the plane appears by now to be a definite feature of galaxies. This allows us to speculate on the reason for this, namely either the fall off in magnetic field strength or deficiency in high energy electrons at high z-distances. Possibly both of these causes are responsible. A new result is available in the form of a recent 8.6 GHz map of NGC 253 by Beck et al. (1978). In this map a halo of nearly spherical symmetry is seen apparently originating in the nucleus. The thick disc of this galaxy, seen at lower frequencies, presumably is supported by electrons originating in SNRs and diffusing from the plane of the galaxy, while the nuclear activity seems to power the young halo.

Supernova remnants are found predominantly in a narrow strip of sky along the galactic plane. Some 125 remnants are known with more suspected remnants awaiting confirmation. Recent studies by Clark and Caswell (1976) in fact showed that up to 30% of SNRs in older catalogues were false identifications. At present good observational data of a homogeneous sample is available for $\delta < 18^o$ only. Recently interest in large low surface brightness objects has been awakened by the ability of modern instruments to map these weak objects. An analysis by Henning and Wendker (1975) of the 408 MHz survey indicated that there were no extended SNRs having $\Sigma_{408} > 1.5 \times 10^{-22}$ W m^{-2} ster^{-1} Hz^{-1}. A recent analysis of the source G65.2+5.7 in Cygnus by Reich et al. (1978) disproves this. Further new objects should be added to the lists soon. Evidence for a class of SNRs resembling the Crab nebula has been put forward by Weiler and Wilson (1977). The origin of cosmic rays is still intimately tied up with the rate of supernova remnants. The figures vary from 30 years to ∿ 150 years between events, but the energy production appears to be sufficient to power the nonthermal radio emission.

Over 300 pulsars are now known. The recent Molonglo survey, announcing the discovery of 155 new pulsars (Manchester et al., 1978) has given us a very homogeneous sample. The period distribution for the new pulsars is similar to that for previously known pulsars. None of the new pulsars has a very short period, but several have periods in excess of 2 sec. Some pulsars have been found with dispersion measure DM > 500 cm^{-3} pc but none with extremely high DM. It appears that all the known facts about distribution are only confirmed. We have the clustering of the pulsars along the galactic plane and a local more isotropically distributed pulsar population. The connection between SNR and pulsar, so definite in Crab nebula is not so clear in all other cases.

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DISCUSSION

Tinsley: Dr. Wielebinski commented that there are "too many pulsars and too few supernova remnants". Would he expand on this remark?

Wielebinski: The rates of SNR formation given by various authors lie in the 30-100 years range. Considerations of pulsar beaming leads us to conclude that pulsar occurrences are one every 5-7 years. This is the discrepancy.