Chapter 1

INTRODUCTION

Radio Astronomy began at low frequencies. It may be recalled that the historic observations of Karl Jansky were done at 20.5 MHz (Jansky 1932). Interestingly, the next major observations by Grote Reber were done at a much higher frequency of 160 MHz (Reber 1940) and this has been the general trend ever since. The main motivation for this was, of course, the quest for higher and higher resolution ; this was easier to achieve at higher frequencies for obvious reasons. The discovery of aperture synthesis only accelerated this trend. On the other hand, the quest for higher resolution and higher sensitivity at lower frequencies was hindered by the fact that the construction and maintenance of large arrays proved to be difficult. Although the technique of "synthesizing" a large aperture was available, it was rendered less useful at low frequencies by the fact that the interference introduced by the ionosphere and terrestrial sources was highly variable over the sort of time scales that would be required to synthesize a large aperture.

Notwithstanding these formidable,difficulties there were many early attempts to observe the sky at low frequencies. For example, as early as 1961 Shain, Komesaroff and Higgins (1961) mapped a part of the Galactic plane st 19.7 MHz with $1^\circ.4$ resolution using the Mills Cross. Five years later, Williams, Renderdine and **Baldwin** (1966) at Cambridge used the aperture synthesis technique to map the northern sky at 38 MHz with a resolution of $0^\circ.7$. In the mid 1970s Erickson and his collaborators used the Clark Lake telescope to make observations of selected regions and obtained accurate fluxes of point sources (Viner and Erickson 1975). In this context, some earlier attempts to determine the fluxes of point sources should also be mentioned: The Penticton array was used at 10.03 MHz by Bridle and Purton (1968) and at 22.25 MHz by Roger, Costain and Lacey (1969) and the UTR radio telescope in Ukraine was used in the frequency range 10 - 25 MHz by Braude et al. (1969). No account of low frequency radio astronomy, however brief, would be complete without a mention of Grote Reber's work in later years (1961) in Tasmania making the lowest ever frequency observations. Through a hole in the ionosphere he started observations of the sky at 2 MHz.

Turning now to the Indian scene, here, too, the first efforts were at relatively higher frequencies. The Ooty radio telescope was built to operate at 327 MHz and the lunar occultation technique was used to make high resolution observations of radio galaxies (Swarup et al. 1971). In the mid 1970s the first low frequency array in India was built at Gauribidanur (latitude $13^\circ 36' 12'' N$) near Bangalore. This array is made up of 1000 dipoles arranged in the form of the letter 'T' with a 1.4 km long East-West arm and 0.45 km long Southern arm. It has a collecting area of ≈ 18000 m^2 while operating at 34.5 MHz. Although the telescope was built to be used in the synthesis mode, the early observations used it as a single beam transit instrument, The array could be phased electronically to the desired declination and the outputs of the East-West array and of the Southern array were multiplied in a single channel analog receiver to produce a pencil beam with a resolution of $21' \times 33'$ at zenith. A sequential scanning of 16 declinations with a minimum separation of $0^\circ.2$ between the beams was adopted for mapping a few localised sources (Sastry et al. 1981 ; Dwarakanath et al. 1982; Sastry and Shevgaonkar 1983; Deshpande et al. 1984; Deshpande and Sastry 1986).

As mentioned above, the main objective in building this telescope was to use it as a synthesis instrument to survey the sky. Ideally, one would have liked to do a 2-dimensional synthesis. But in view of the complexity of the hardware required to do such an observation, as a first effort it was decided to do a 1-dimensional synthesis along declination. With this in view, a 128-channel digital receiver system was built by Ravindra and Udayashankar and installed at Gauribidanur in 1983 (the details of the receiver system may be found in the theses by Ravindra 1983 and Udayashankar 1986). Though this receiver system was primarily used for continuum observations, it was also used in the autocorrelator mode to observe pulsars (Deshpande 1987) and radio recombination lines (Udayashankar 1986) at 34.5 MHz.

The objective of the present thesis was to map the entire sky observable from Gauribidanur using this receiver system. The declination range of -36° to $+64^\circ$ was covered in the present survey with a resolution of $21' \times 33'$ at the zenith and a sensitivity of 4 Jy (1σ). Using the East-West array in the transit mode, the declination range mentioned above could be mapped in 24 hours of time. This along with choosing the period of observations during the solar minimum alleviated many of the problems plaguing low frequency astronomy such as disturbances due to solar activity, terrestrial interference and the changing ionosphere. Special care was taken to include spatial frequencies all the way down to zero; this enabled us to map the sky at all angular scales.

The details of the instrument used and the observing mode are described in Chapter 2 while the data analysis and calibration are described in Chapter 3. The results of the survey are presented in Chapter 4 in the form of contour maps.

At this stage it is appropriate to mention some of the scientific objectives of this survey. One of the objective was to map the large scale features of the Galaxy. There were, of course, earlier attempts to do this although they had poorer resolution than the present survey. For example, Mathewson, Broten and Cole (1965) used the Parkes telescope to survey the southern sky with a resolution of 11°. Milogradov-Turin and Smith (1973) used the Jodrell Bank telescope to survey the declination range -25° to $+75^\circ$ with a resolution of 8°. Although much of the declination range surveyed by us was covered in the earlier studies, the better resolution possible with the Gauribidanur telescope promised a more detailed spectral index map of the Galaxy through comparison of our observations with the survey at 408 MHz done by Haslam et al. (1982). It may be mentioned here that the 408 MHz survey has a similar resolution to ours.

The pioneering observations of Shain, Komesaroff and Higgins (1961) referred to earlier, and the survey of the southern sky by Jones and Finlay (1974) using the Fleurs synthesis telescope, already showed several absorption features in the Galactic plane due to the presence of thermal gas. More recently, some of the most important results obtained by the Infra-Red Astronomical Satellite (IRAS) pertain to the distribution of this gas (Beichman 1987). A detailed mapping of this thermal gas which is expected to be seen in absorption against the intense synchrotron background was one of the main objectives of the present study. Chapter 6 is devoted to a discussion of the distribution and the parameters of this gas as deduced from our observations.

One of the most spectacular discoveries in recent times has been that of the millisecond pulsars. It may be recalled that the discovery of the first millisecond pulsar in the Galactic disk, as well as the first one in a globular cluster, can be traced to the discovery of point sources with very steep spectra at low frequencies (Erickson 1983; Mahoney and Erickson 1985). Various theoretical attempts to understand the origin and evolution of millisecond pulsars predict a substantial number of them in the Galaxy; indeed, their population may exceed that of the normal pulsars (Bhattacharya and Srinivasan 1986; Kulkarni and Narayan 1988). If the 1.5 millisecond pulsar (PSR 1937+21) is 'typical' of the population, then in a reasonably sensitive survey such as ours one could hope to detect them as steep spectrum sources. If not, one would be learning something about the luminosity function of the millisecond pulsars.

Although the goals mentioned in the above two paragraphs refer to regions within, say, ± 20 degrees of the Galactic plane, there is also considerable interest in regions far from the plane of the Galaxy. In recent times there has been renewed interest in the source counts as well as in the large scale distribution of extragalactic sources. In all these discussions the main observational input has been the results of surveys done at relatively high frequencies. It may be of some interest to do a similar analysis based on the observations of extragalactic sources at a much lower frequency. There could in principle be differences in the source counts, as well as in the angular distribution. For example, some of the sources seen at low frequencies may not form a part of the population seen at higher frequencies; this can happen if they have a very steep spectrum. The present survey with its wide coverage and uniform sensitivity is of particular interest in this context.

While we have enumerated several scientific objectives which justify a large survey such as the present one, in this thesis we wish to confine our discussion to one particular topic. This concerns the nature of the thermal gas seen in absorption in the Galactic plane. In Chapter 6 we argue that this gas must be fairly near-by. He also suggest that much of the low velocity and low frequency (such as the H 272α line) radio recombination lines could well originate in this gas. In future studies we will attempt a detailed correlation between our data, the recombination line observations and the IRAS survey. An analysis of our data with a view to identifying possible candidates for millisecond pulsar searches, as well as a study of the statistics of extragalactic sources are also deferred to future studies.

Table 1.1 Some of the mapping efforts made at low frequencies

Freq. (MHz)	Size	Observatory	Resol. (deg.)	Coverage	Reference
19.7	'+' Array 1.6 km EW 1.6 km NS	Mills cross	1.4	$224^\circ < l < 16^\circ$ $-6^\circ < b < +6^\circ$	Shain, C.A. Komesaroff, M.M. Higgins, C.S.(1961)
38	Array 1 km EW Movable NS	Cambridge	0.75	$-10^\circ < \delta < +90^\circ$ 24 Hr in RA	Williams, P.J.S. Kenderdine, S. Baldwin, J.E.(1966)
29.9	Array 1 km EW Movable NS	Fleurs, NSW	0.8	$225^\circ < l < 30^\circ$ $-10^\circ < b < +10^\circ$	Jones, B.B. Finlay, E.A (1974)
10	'T' Array 1.2 km EW 0.7 km NS	Penticton	2.0	$-5^\circ < \delta$ 24 Hr in RA	Caswell, J.L. (1976)
30.9	'T' Array 3 km EW 1.8 km NS	Clark Lake	0.2	$350^\circ < l < 250^\circ$ $-3^\circ < b < +3^\circ$	Namir E. Kassim (1988)
30	Single dish 210 ft.	Parkes	11	$-90^\circ < \delta < 0^\circ$ 24 Hr in RA	Mathewson, D. Broten, N.W. Cole, D.J. (1965)
38	Single dish 250 ft.	Jodrell	8	$-25^\circ < \delta < +70^\circ$ 24 Hr in RA	Milogradov-Turin, J. Smith, F.G.(1973)

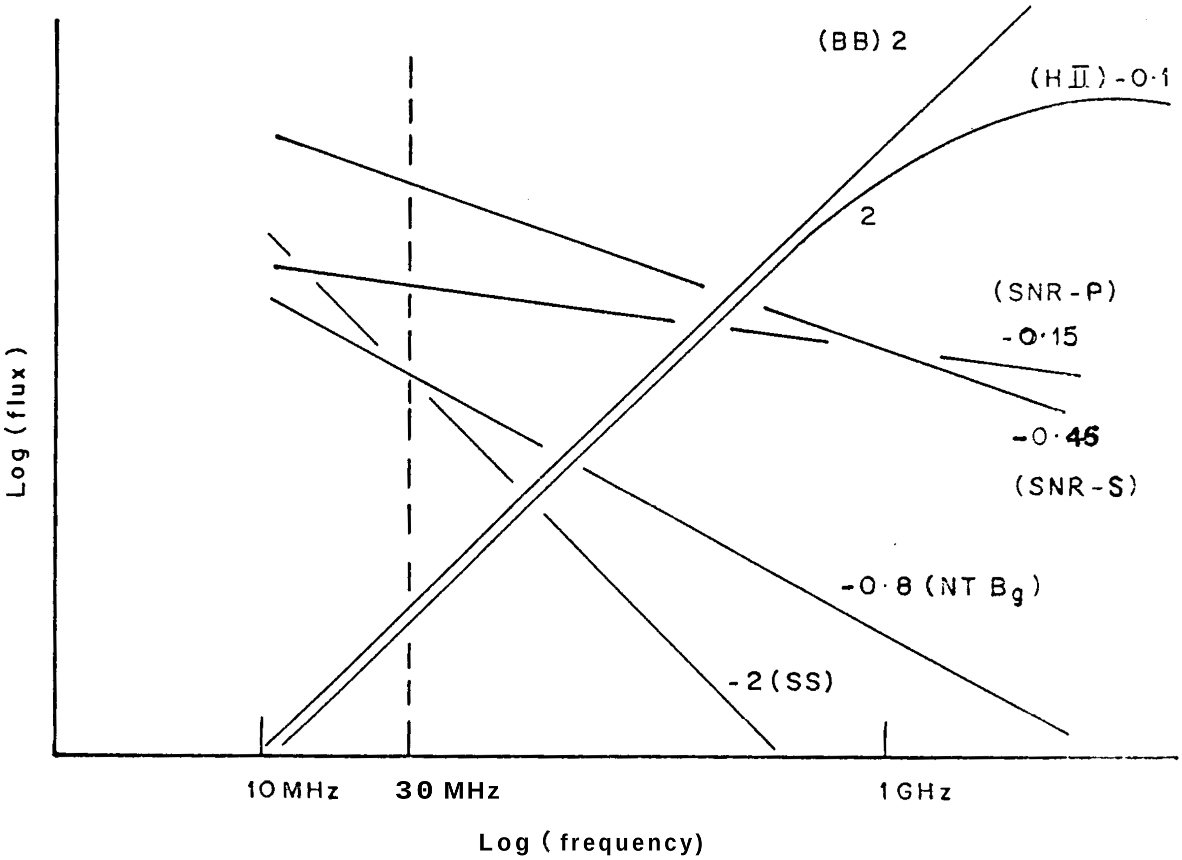

Fig. 1.1: Spectral behaviour of different kinds of sources. 'BB' refers to black-body emission at a certain temperature. Ionized hydrogen regions ('HII') are optically thin at high frequencies but become optically thick at lower frequencies. At frequencies ≈ 30 MHz they appear in absorption against the much brighter non-thermal background ('NT Bg') which has equivalent black-body temperatures ≈20,000 K to 100,000 K. Radio emission from the halos of galaxies or from puslars has a steep spectrum ('SS'). Supernova remnants belong to two classes depending on whether they are powered by an active pulsar ('SNR-P') or by the blast wave (SNR-S').

REFERENCES

Beichman, C.A. 1987, Ann. Rev. Astron. Astrophys., 25,521.

Bhattacharya, D., Srinivasan, G. 1986, Curr. Sci., 55,327.

Braude, **S.Ya.,** Lebedeva, O.M., Megn, A.V., Ryabov, **B.P., Zhouk,I.N.** 1969, Mon. Not. R. astr. **Soc.,** 143, 289.

Bridle, A.H., Purton, C.R. 1968, Astr. J., **73,** 717.

Caswell, J.L. 1976, Mon. Not. R. astr. **Soc.,** **177,** 601.

Deshpande, A.A., Shevgaonkar, R.K., Sastry, **Ch.V.** 1984, Astrophys. Space **Sci.,** 102, 21.

Deshpande, A.A., Sastry, Ch. V. 1986, Astr. Astrophys., 160, 129.

Deshpande, A.A. **1987,** **Ph.D.** Thesis, Dept. of El. Eng., Indian Institute of Technology, Bombay.

Dwarakanath, K.S., Shevgaonkar, R.K., Sastry, **Ch.V.** 1982, J. Astrophys. Astr., 3, 207.

Erickson, W.C. 1983, Astrophys. J., 264, L13.

Haslam, C.G.T., Salter, C.J., **Stoffel,** H., Wilson, W.E. 1982, Astr. Astrophys. Suppl. Ser., **47,** 1.

Jansky, K.G. 1932, Proc. IRE, 20, 1920.

Jones, B.B., **Finlay,** E.A. **1974,** Aust. J. Phys., 27, 687.

Kassim, N.E. 1988, Astrophys. J. Suppl. Ser., 68, 715.

Kulkarni, S.R., Narayan, R. 1988, Astrophys. **J.,335,755.**

Mahoney, M.J., Erickson, W.C. 1985, Nature, 317, 154.

Mathewson, **D.S.,** Broten, N.W., Cole, D.J. 1965, Aust. J. Phys., **18,** 665.

Milogradov-Turin, J., Smith, F.G. 1973, Mon. Not. R. astr. **Soc.,** 161, 269.

Ravindra, D.K. 1983, **Ph.D.** Thesis, Dept. of El. **Com.** Eng., Indian Institute of Science, Bangalore.

Reber, G. 1940, Astrophys. J., 91, 621.

Roger, R.S., **Costain,** C.H., Lacey, J.D. 1969, Astr. **J.,74,** 366.

Sastry, Ch. **V.,** **Dwarakanath,** K.S., Shevgaonkar, **R.K.** 1981, **J.** Astrophys. Astr. **,** 2, 339.

Sastry, Ch.V., Shevgaonkar, R.K. 1983, J. Astrophys. Astr., 4, 47.

Shain, C.A., Komesaroff, M.M., Higgins, C.S. 1961, Aust. J. Phys., 14, 508.

Swarup, G., Sarma, N.V.G., Joshi, M.N., Kapahi, V.K., Bagri, D.S., Damle, S.H., Ananthakrishnan, S., Balasubramanian, V., Bhave, S.S., Sinha, R.P. 1971, Nature, 230, 185.

Udayashankar, N. 1986, Ph.D. Thesis, Dept. of Physics, Bangalore University, Bangalore.

Viner, M.R., Erickson, W.C. 1975, Astr. J., 80, 931.

Williams, P.J.S., Kenderdine, S., Baldwin, J.E. 1966, Mem. R. astr. Soc., 70, 53.