Large Scale Surveys of the Galaxy

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Abstract The radio emission from normal galaxies is weak and requires the largest telescopes to observe them. In principal the best case to study normal galaxies is our own one. However, our unfavourable location within the Galaxy makes it necessary to conduct large-scale surveys at different frequencies in order to derive physical properties of the Galaxy.

For a long time the 408 MHz all-sky survey and the 1420 MHz survey of the northern sky have been the most reliable surveys to perform these studies. In the last years the 1420 MHz survey has been extended to an all-sky survey. Also at 22, 45 and 2625 MHz large portions of the Galaxy were recently mapped, so that there is an unprecedented database for Galactic studies available today. However, some care must be taken when comparing these surveys as they come from rather different telescopes and use different observing techniques.

1 Introduction

Since the beginning of radio astronomy radio continuum surveys at different frequencies have been conducted in order to study our own Galaxy. For example the parameters of the thin and the thick disk or halo were modelled. With these global parameters of the Galaxy, comparisons with those from other galaxies are possible. The spectrum of the radio emission can be computed and a separation of the thermal and non-thermal emission can be made. Surveys provide an overall view to large local features extending up to 100° like the prominent North Polar Spur (NPS). Other large supernova remnants, HII region complexes, loops and spurs are also outstanding features in the survey maps and can be studied in some detail.

Beyond astronomical applications surveys are important in other fields. The Galactic background is a major source of noise at low frequencies and sets the limit for receiver sensitivities other than technology, which constrains the sensitivity in the high frequency range. It was recently realised that the 1.4 GHz surveys are of special interest for coming 1.4 GHz satellite measurements of the ocean salinity or soil moisture, because these radiometers pick up Galactic emission by their sidelobes and ground reflections (Kerr et al. 2002 and references therein). Furthermore surveys give a comprehensive overview of the Galactic foreground emission, which has to be subtracted from cosmic microwave background measurements before studies of its fine structure for cosmological information. Finally absolutely calibrated sky surveys are needed to add missing large-scale components to interferometric data. Also relative measurements of limited fields made with large single dishes like the Effelsberg telescope gain from adding correct large-scale structures.

2 The Surveys

In the following surveys will be described which at least cover a third of the sky and include emission on all scales. This excludes high resolution source surveys by interferometers or single dishes. Finally the surveys need to be available in numerical form, which excludes a number of older maps. More information and discussions of previous surveys were already provided e.g. by Salter & Brown (1988) and by Reich (1990).

For 20 years one all-sky survey was available to the astronomical community, namely the 408 MHz survey by Haslam et al. (1982). In the eighties the 1420 MHz survey of the northern sky was published (Reich 1982; Reich & Reich 1986), and then it took more than ten years to publish more large-scale surveys at other frequencies. At the low-frequency end a 22 MHz survey of the northern sky (Roger et al. 1999), at 45 MHz first the southern sky survey, and then the northern sky survey (Alvarez et al. 1997; Maeda et al. 1999) were finished. At the high-frequency end first the southern sky at 2326 MHz (Jonas, Baart, & Nicolson 1998) and later at 1420 MHz was published (Reich, Testori, & Reich 2001). Merging of the 1420 MHz maps in the southern and northern sky gives an all-sky survey superior in angular resolution and sensitivity when compared to the 408 MHz survey. Tables 1 and 2 list some basic parameters of the above mentioned surveys.

Table 1 Large-scale surveys of the Galaxy: basic parameters 1

Frequency (MHz)	HPBW (°)	Coverage	Authors
22	1.1×1.7	$-28^\circ \leq \delta \leq +80^\circ$	Roger et al. 1999
45	3.6	$+5^\circ \leq \delta \leq +65^\circ$	Maeda et al. 1999
45	4.6×2.4	$-86^\circ \leq \delta \leq +19^\circ$	Alvarez et al. 1997
408	0.85	all-sky	Haslam et al. 1982
1420	0.59	$\delta \geq -19^\circ$	Reich 1982; Reich & Reich 1986
1420	0.59	$\delta \leq -10^\circ$	Reich, Testori, & Reich, 2001
2625	0.333	$-83^\circ \leq \delta \leq +13^\circ$	Jonas, Baart, & Nicolson 1998

Table 2 Large-scale surveys of the Galaxy: basic parameters 2

Frequency (MHz)	Sensitivity	Available from
22	5000 K	tom.landecker@nrc.ca
45	250 K	maeda@hcmern.hyo-med.ac.jp
45	250 K	halvarez@das.uchile.cl jmay@das.uchile.cl
408	2 K	www.mpifr-bonn.mpg.de/survey.html
1420	50 mK	www.mpifr-bonn.mpg.de/survey.html
1420	50 mK	www.mpifr-bonn.mpg.de/survey/plots.html
2625	30 mK	J.Jonas@ru.ac.za

The 820 MHz survey of the northern sky by Berkhuijsen (1972) is not listed in the tables, because its original resolution of 1° .2 is degraded to 5° to increase the signal-to-noise ratio in the low-intensity area between 150° and 270° in Galactic longitude and roughly 30° and 50° to 70° in latitude. However, this survey is also available at http://www.mpifr-bonn.mpg.de/survey.html together with other Galactic plane surveys not being discussed here.

2.1 The Telescopes

The surveys have been realised by using technically quite different telescopes. The 22 MHz survey was observed at the Dominion Radio Astrophysical Observatory in Penticton (Canada). The T-shaped telescope consists of 624 full-wavelength dipoles and has an extent of 1310 × 443 m (Costain, Lacey, & Roger 1969).

The 45 MHz survey of the southern sky was observed at Maipu in Chile. There 528 full-wavelength east-west orientated dipoles are arranged in a rectangular field of 106 × 73 metres (May et al. 1984).

The 46.5 MHz survey of the northern sky was conducted with the MU-Radar located in Shigaraki (Japan), where 475 crossed 3-element Yagis are arranged in a circle with a diameter of 103 metres (Fukao et al. 1985a, 1985b).

The 408 MHz survey was combined from maps made with three large single-dish telescopes at Jodrell Bank (England), Effelsberg (Germany) and Parkes (Australia).

The 1420 MHz survey of the northern sky was carried out with the 25-m Stockert telescope of Bonn University (Reich 1977). The southern sky has been observed using a 30-m antenna at Villa Elisa (Testori et al. 2001) located in the southern area of Buenos Aires (Argentina).

The 2326 MHz survey of the southern sky came from the 26-m antenna at Hartebeesthoek (Jonas 1999) in South Africa, which is 1100 km away from the supervising Rhodes University.

Most of the low-frequency antennas are located at quite remote, isolated places in order to avoid man-made interference, which is an increasing problem at higher frequencies as well. As a consequence the Stockert 25-m telescope was closed at the end of the eighties.

2.2 The Observation Techniques

The observing techniques for the surveys were as different as the telescopes used. The low-frequency surveys utilise sky rotation at constant declinations to cover the sky. The 2326 MHz survey has been observed exactly orthogonally by moving the telescope along declination. The 1420 MHz survey of the northern sky is made from azimuth scans at three different fixed elevations. The "nodding scan technique" (Haslam et al. 1974), which is rather efficient to reduce receiver drift effects, has been applied for most parts of the 408 MHz survey and also for the 1420 MHz survey of the southern sky. Nodding scans were collected by moving the telescope up and down in the meridian and use the sky rotation to cover large areas. Starting this continuous procedure for a sequence of nights at different sidereal times gives a fully sampled grid of data, where up and down scans intersect.

3 The 1420 MHz Survey

A 1420 MHz all-sky survey map has been combined by adding the northern and southern survey in the overlapping area in such a way that the weight of each survey decreases as its declination is reaching the survey's limit. In that way discontinuities at $\delta = -10°$ or at $\delta = -19°$ were avoided. Fig. 1 shows this survey, for clarity degraded to a resolution of 2°, in an equal-area projection in Galactic coordinates centered at the Galactic Centre. The contours are running in steps of 50 mK up to 4.4 K, 100 mK up to 6.0 K, 250 mK up to 7 K, 500 mK up to 10 K and in steps of 1 K further on. Contour labels are in K T_B (full beam brightness). Arrows on contours point towards local minima. The map is at an absolute scale, where the cosmic microwave background and unresolved sources contribute in total by 2.8 K T_B.

The maximum emission along the Galactic plane reflects the high concentration of emission in the Galactic disk. At 2° angular resolution most source complexes merge with the diffuse unresolved emission. The local spiral arm towards Cygnus and Vela (longitudes about 90° and 270°, respectively) clearly show up. Our position at about 8 kpc distance from the Galactic Centre allows to trace the enhanced high latitude emission from the inner Galaxy and quite weak emission towards the Galactic anticentre direction.

In Fig. 2 some well-known individual features are labelled on a 1420 MHz map with just a few selected contours. The most intense feature sticking out of the Galactic plane at about 30° Galactic longitude is the North Polar Spur (NPS). It is believed to be the relic of a very old SNR located at just about 200 pc distance. A comprehensive review on the NPS was made by Salter (1983). In contrast, the two historic supernova remnants, the Crab nebula and Cas A, are the two strongest unresolved sources in the sky.

The Galactic Centre Spur (GCS) is the second strongest spur in the map following the

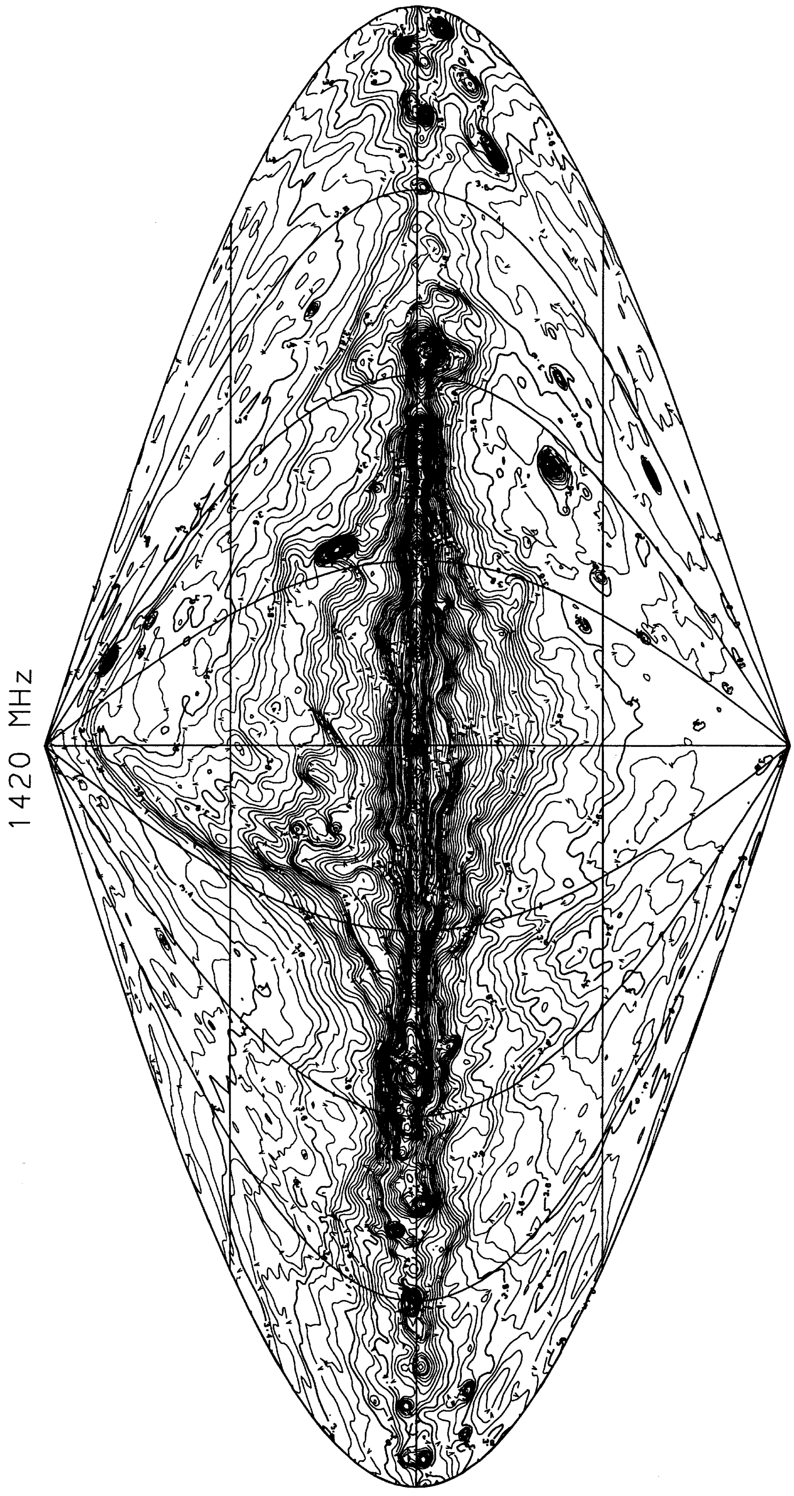

Fig. 1 The 1420 MHz all-sky survey at a resolution of 2°

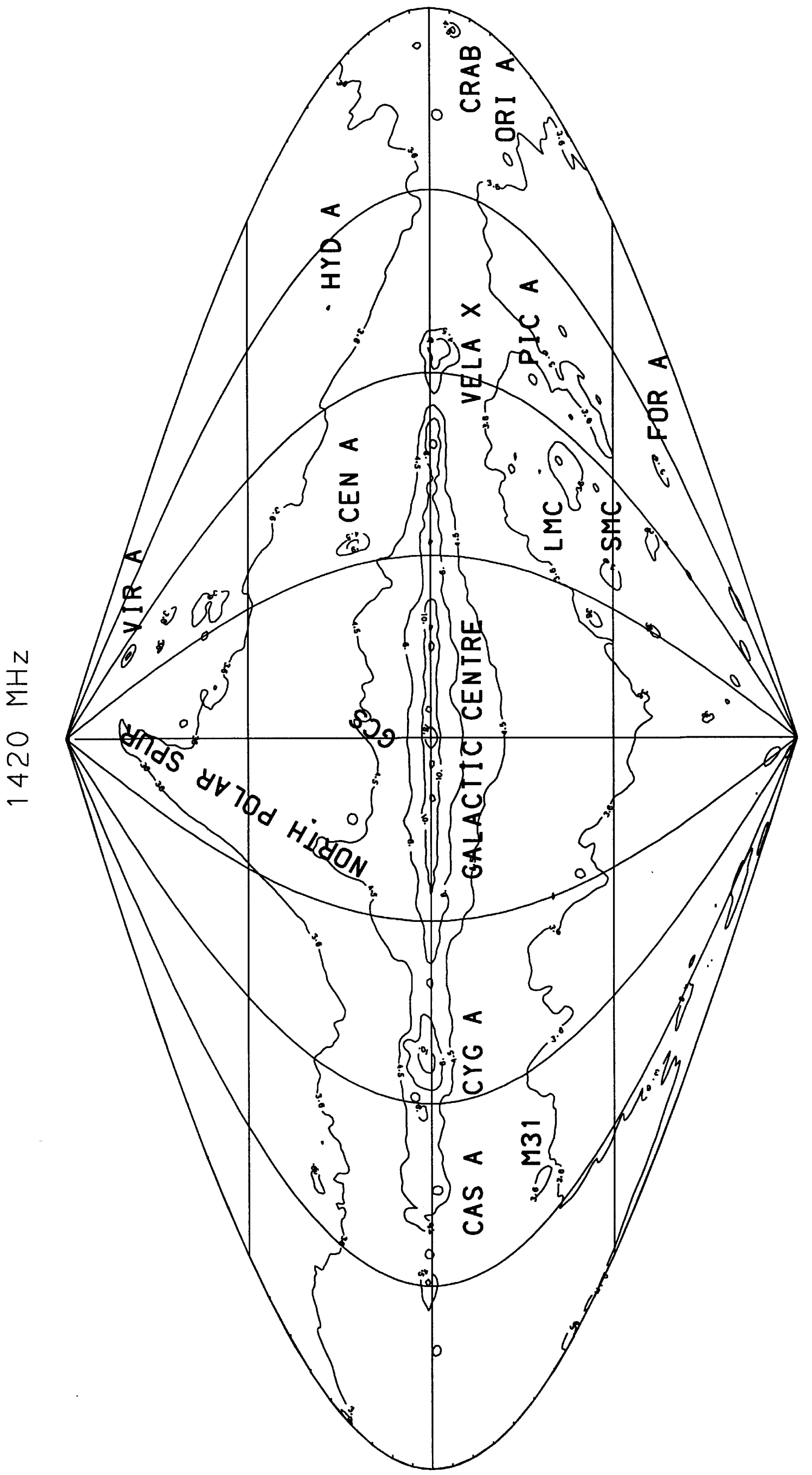

Fig. 2 Sketch of some prominent structures seen in Fig.1

NPS reaching out of the Galactic plane for more than 20° . It can be traced on maps with higher angular resolution to about 1° distance to the Galactic Centre and was proposed by Sofue, Reich, & Reich (1989) to be emerging from there. In that case it is a well collimated feature with a length of 4 kpc and a width of just 200 pc.

Some nearby galaxies as the Large Magellanic Cloud (LMC), the Small Magellanic Cloud (SMC) and M31 (Andromeda Galaxy) are visible as distinct sources at high Galactic latitudes. A number of strong radio galaxies are marked in Fig. 2 too. The rather extended and partly resolved radio galaxy Centaurus A has recently been rediscussed by Alvarez et al. (2000) including data from the surveys listed in Table 1.

4 The Spectral Index Distribution

Spectral indices can in principle be calculated from any pair of surveys, although a careful analysis of all the calibration properties like scaling, zero-level adjustments and systematics from the observing method must be made to obtain reliable results. For example, such an analysis was made by Reich & Reich (1988a) who derived a spectral index map between 408 MHz and 1420 MHz for the northern sky. Significant spectral index variations were noted, reflecting the mixture of thermal and synchrotron emission along the Galactic plane. The changes in the energy spectrum of the relativistic electron component in the Galaxy also cause spectral variations. A particular puzzling feature of this spectral index map is the spectral flattening towards high latitudes in the Galactic anticentre, which was interpreted by Reich & Reich (1988b) as evidence for a Galactic wind. This could be interpreted in terms of the cooling-convection halo models proposed by Lerche & Schlickeiser (1982). Extending this work by including the new southern sky data at 1420 MHz confirms qualitatively the same spectral behaviour for the southern sky (Reich et al., in prep.).

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