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A 45-MHz continuum survey of the southern hemisphere

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Abstract. We present a survey of the 45-MHz continuum emission south of $\delta = +19.1°$. The observations were made with a transit array having a beam $4.6°(\alpha) \times 2.4°(\delta)$, full width at half maximum (FWHM). The results are given in sets of maps in galactic and equatorial coordinates (Epoch 1950).

Key words: radio continuum: ISM — surveys — Galaxy: structure — cosmic rays

1. Introduction

The continuum radio emission of the sky background is a mixture mainly of thermal (free-free) and non-thermal (synchrotron) components, in a proportion that depends on the observing frequency. At frequencies higher than about 1 GHz the largest fraction of the radiation is thermal, and this fraction decreases with frequency. At intermediate frequencies, roughly a few hundreds of MHz, the nonthermal radiation begins to dominate and continues to do so with decreasing frequency until the absorption by ionized hydrogen sets in at about a few tens of MHz. Studies of many astrophysical processes in our Galaxy rely on the separation of the two components. For example, since the synchrotron emission results from the interaction of the galactic cosmic ray electrons with the galactic magnetic fields, its study is important to learn about the distribution and energy spectrum of the energetic electrons, as well as about the distribution of the magnetic fields. The identification of the components has recently received special attention in the study of anisotropies of the cosmic microwave background (Kogut et al. 1996; Davies et al. 1996). The separation of the thermal and nonthermal components has been a problem not satisfactorily solved so far. In spite of the advantage that low-frequency observations (≤ 100 MHz) offer in this respect, very few surveys have been made in this frequency range, probably because of the many inherent difficulties. For example, it is necessary to build very large arrays in order to achieve good angular resolution, this usually limits the telescopes to be only transit instruments; the interference (man-made and natural) is a severe problem; the ionosphere can produce considerable changes in the incomig signal; depending on the design of the array the observations may be strongly affected by meteorological conditions (fog, rain, etc.). The design of the array imposes also limitations on the amount of sky that the instrument can cover. Ideally a survey should cover the whole sky, the observations should be made with instruments of similar characteristics and observing at the same frequency.

Most of the available galactic continuum surveys cover the galactic plane only. The few surveys covering the whole southern sky below 408 MHz and with single frequency observations are listed in Table 1. It is seen that half of the surveys have a very low angular resolution ($> 11°$). The fourth column lists the temperature step between adjacent contours lines near a minimum at $\alpha \approx 5^{\rm h}$, $\delta \approx -60°$, the fifth column shows the percentage of the background temperature corresponding to that step. This number intends to estimate the sensitivity of the system.

Realizing the need of low-frequency observations the University of Chile begun in 1970 the construction of a large array tuned at 45 MHz (Reyes 1977), with the purpose, among others, of making a sky survey. Preliminary results were reported by Bitran (1981), and Bitran et al. (1981). The first results of the survey were presented by Alvarez et al. (1988).

2. Observations

The observations were made with the 45-MHz array of the University of Chile at the Maipu Radio Astronomy Observatory ($33°30'05''$S, $70°51'28''$W). Since the instrument has been described in detail elsewhere (May et al. 1984; Alvarez et al. 1994), only a brief description will be given here. The main parameters of the array are presented in Table 2.

The array is made up of 528 full-wavelentgh dipoles oriented E-W and distributed in six groups, where the signal after passing through a balun-preamplifier is fed to a matrix of hybrid rings. This matrix produces a set of beams staggered along the meridian and separated

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Table 1. Continuum surveys covering the whole southern hemisphere below 408 MHz

ν (MHz)	Coverage (δ) (°)	Resolution (α, δ) (°), (°)	ΔT (K)	$\Delta T/T$ (%)	Instrument	Reference
200	-85 - $+45$	25×25	16	100	array	Allen & Gum(1950)
153	-90 - $+10$	2.2×2.2	20	13	dish	Hamilton & Haynes (1969)
100	-90 - $+30$	17×17	50	9	array	Bolton & Westfold (1950)
85	-90 - -20[a]	3.8×3.5	100	10	dish	Yates et al. (1967)
45	-86.1 - $+19.1$	4.6×2.4	250	6	array	This survey
30	-90 - 0	11×11	1800	25	dish	Mathewson et al. (1965)
16.5	-90 - 0	1.5×1.5	$2\,10^4$	25	array	Ellis (1982)
to		to				
2.1		7.5×7.5	10^6	25		

[a] This survey can be complemented with that of Landecker & Wielebinski (1970) made with the same instrument at the same frequency, and covers the range $-25° \leq \delta \leq +25°$.

Table 2. Parameters of the radio telescope

Operating frequency	45.00 MHz
Angular resolution (FWHM)	$4.6°(\alpha) \times 2.4°(\delta)$
Polarization	E-W linear
Effective area at the zenith	11200 m^2
Sensitivity at the zenith	3.9 K/Jy
Bandwidth	1 MHz
Receiver noise temperature	300 K
Array coordinates	33°30′05″ S, 70°51′28″ W

approximately by 1.8°. The beams produce simultaneous and independent outputs and can be steered in declinations by electric phasing. Since only the four central beams were used, the array scanned the sky along four declinations spanning a strip about 5.4° wide at a time. The sky was covered by moving the set of beams to adjacent positions separated by 5.4° (called "nominal" positions), in such a way that the end-beams overlapped thus producing the anchorage of the observations. The antenna behaves well approximately within 50° from the zenith so, in all, 19 equidistant nominal positions covered the range $-86.1° \leq \delta \leq +19.1°$. At the beggining of a new declination run we checked for possible errors in the electric phasing of the array by observing intense radio sources or the transit of the galactic equator, if there was no source. Since low-frequency observations are very sensitive to ionospheric conditions, as well as to man-made and natural interference (the solar maximum around 1989 was particularly devastating), each position was observed for several weeks in order to obtain the best possible data. Also, because of increasingly adverse observing conditions each position was observed several times. To help in eliminating diurnal and seasonal effects, each position was observed in epochs separated by odd multiples of six months. The observations began in 1982 and ended in 1994.

An internal calibration signal from a noise generator was injected automatically every hour through the balun-preamplifiers located at the array site, and the temporal drift in gain of the preamplifiers and receivers was corrected by linear interpolation. In order to make a reference calibration we observed a region of the sky ($\alpha = 19^{h}00^{m}$, $\delta = +5°$) well covered with observations at different frequencies. The best fit to the spectral data gives 30000 K which agrees well the 29500 K we measured. The bandwith and sensitivity (at the zenith) were 1 MHz and 3.9 K/Jy, respectively. Data points in right ascension were acquired every 10 seconds and were integrated over one minute. The integrated temperature value was asigned in time to the middle of the minute.

3. Data reduction

The data consists of a large number of constant declination scans (antenna temperature profiles) 24-hour long, and separated approximately by 1.8°. Many of the effects that mar the data can be readily recognized, and often corrected, because of their short time scale (e.g. solar bursts, radio stations). Meteorological effects like rain and fog can be eliminated simply by not observing under those conditions. Some ionospheric effects produce smooth fluctuations of the order of ten minutes and can be present for hours. These effecs cannot be corrected so the affected data are rejected. Other ionospheric effects result in slow variations of the incoming signal with a time scale of many hours, and we attribute them to changes in the opacity of the ionosphere. As a result of the combined effects just discussed the temperature profiles observed for a given declination are not quite repetitive. In order to minimize the ionospheric absorption, for each pointing we selected the best data and drew the envelope to them; this envelope was then accepted as the true profile for the corresponding declination. Similar procedure have been followed by Yates & Wielebinski (1966) and Briddle & Purton (1968). As it is explained in detail elsewhere (Alvarez et al. 1994), contrary to what we had assumed at first from a study of the antenna pattern near the zenith, we found by precise measurements that the separation between beams is not constant at 1.8°, but that it increases with zenith distance up to 2.6° at −48.6° ($\delta = -82.1°$). In matching the data by overlapping end-beams of adjacent positions we adopted the criterion of averaging the temperatures measured by the two beams, and of asigning that value to the average of their declinations. In this way we tried to minimise the scanning effects in the final map. In all we used 58 different declinations. We also found that the azimuth of the N-S axis of the array (measured from north towards the east) is −0.55°, and that the plane of the array is inclined 0.47° toward the east (Alvarez et al. 1994). These parameters were used to correct the observed right ascensions. The data were also corrected by side lobe effects; this was accomplished by computing theoretically the array radiation pattern, and by complementing this survey with observations made by Maeda (1994) at 46 MHz and north of $\delta = +19.1°$. Many scanning effects were eliminated by selecting the best data and by reobserving several times the conflicting positions. Residual scanning effects were corrected as much as possible by the method of unsharp masking (Sofue & Reich 1979). The extragalactic radio sources were not removed. We estimate the error in the temperature scale at 10% or better.

4. Presentation of the data

The survey is presented in two sets of maps, in equatorial and galactic coordinates, following approximately the format of Haslam et al. (1982) survey. In equatorial coordinates (1950 Epoch) the survey consists of a set of seven maps covering $-75° \le \delta \le +19°$, 4 hours in right ascension each, and the south polar region $-60° \le \delta \le -90°$ (Fig. 1). A grid of galactic coordinates is superposed to each map. In galactic coordinates the survey consists of a set of eight maps (Fig. 2). Six maps cover the longitude ranges $180° \le l \le 300°$ and $300° \le l \le 60°$, and the latitude ranges $90° \le b \le 25°$, $30° \le b \le -30°$, and $-25° \le b \le -90°$. Two additional maps cover the galactic poles in the ranges $60° \le b \le 90°$, and $-60° \le b \le -90°$. A grid of equatorial coordinates is superposed to each map.

The contour lines correspond to brightness temperature and are labelled as follows: up to 6000 K in 250 K steps, labelled every 1500 K; from 6000 K to 10000 K in 400 K steps, labelled every 2000 K; from 10000 K to 20000 K in 1000 K steps, labelled every 10000 K; from 20000 K to 76000 K in 2000 K steps, labelled every 20000 K.

Arrows on contour lines indicate directions of decreasing temperature. Figure **??** presents contour lines for the whole survey in equal-area projection of galactic coordinates. Figure 4 shows a color coded map of the whole survey in equal-area projection of galactic coordinates.

5. Discussion

Since the transmission line network of the Maipu array uses open air tween-lines the observations are very vulnerable to meteorological conditions. This, and other undesirable effects mentioned earlier, meant that we had to observe for 12 years in order to get data of good quality. The ever increasing man-made interference will certainly make low-frequency observations far more difficult, if not impossible, in the future. At this time we are working with Dr. Koitiro Maeda in the processing of 46-MHz data he took in the northern hemisphere with an instrument of characteristics similar to ours. If these data are found to be of quality comparable to that of the present southern survey, we plan to produce an all-sky survey at 45 MHz.

The operating frequency at 45 MHz was chosen because the Chilean government allocated a 3-MHz band centered at that frequency for radio astronomy use only. This proved to be a very convenient choise because we found that it is not too high to be contaminated with thermal emission, nor too low to be affected by thermal absorption (Alvarez et al. 1987). Therefore we believe the survey represents practically pure synchrotron emission.

The survey shows numerous interesting galactic features like arcs, spurs, filaments and loops some of which are also seen at 408 MHz. The most significant difference with Haslam et al. (1982) survey is that this shows the maximum brightness at the galactic centre ($l \approx 0°$, $b \approx 0°$) while ours shows it at $l \approx 2°$, $b \approx 0°$. A preliminary discussion of this feature has been presented by us elsewhere (Alvarez et al. 1996).

The 45-MHz survey should be useful in studying galactic structure and procesess through comparisons with the distribution of high energy particles and magnetic fields, and with surveys at other wavelengths.

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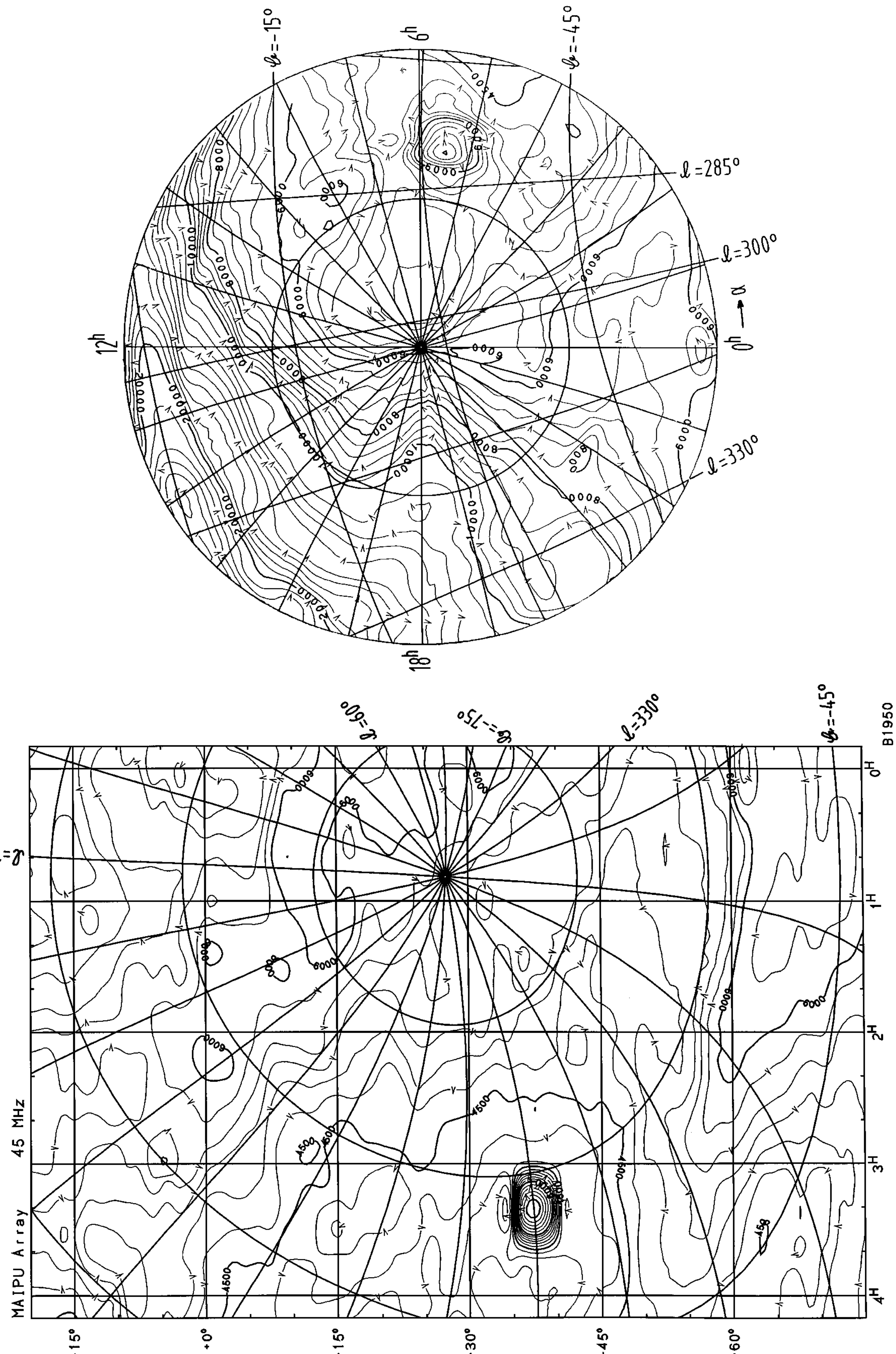
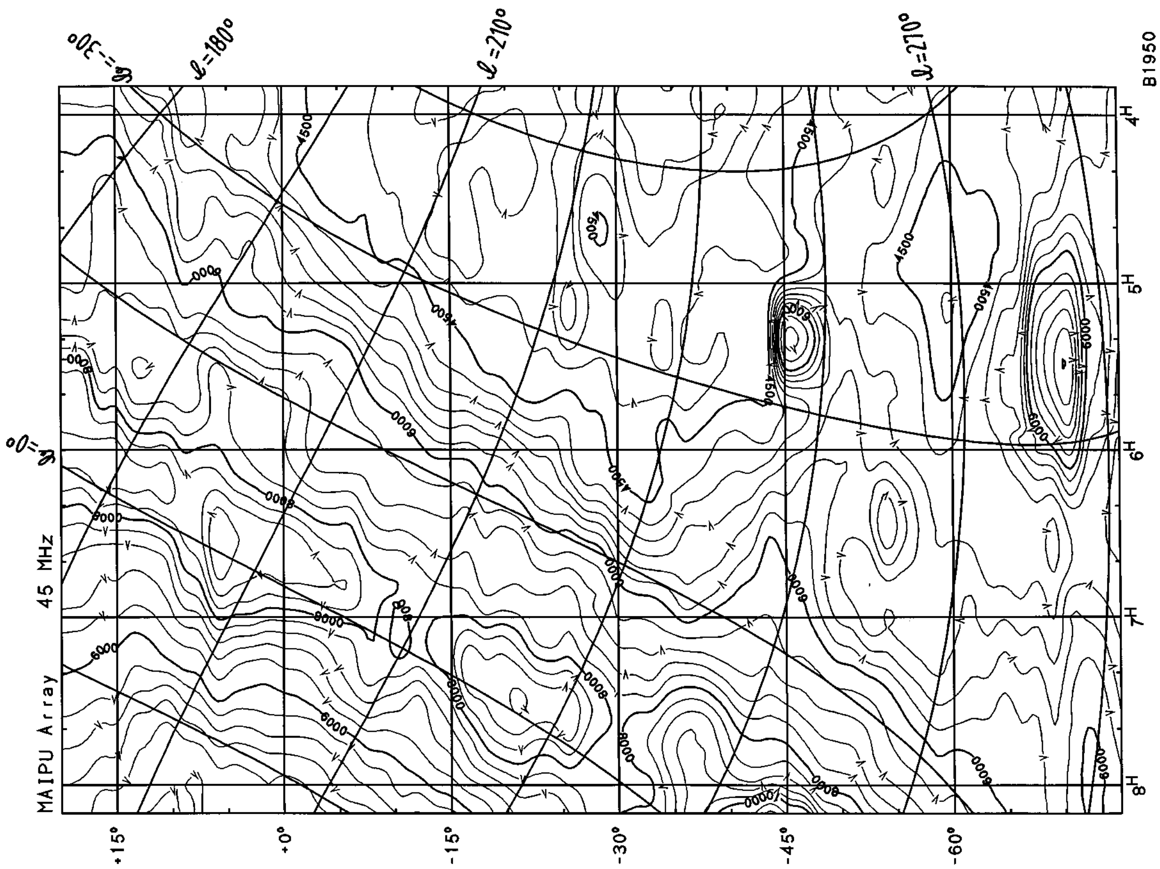


Fig. 1. Set of maps of the 45-MHz survey in equatorial coordinates (Epoch 1950). The explanation of contour levels and labelling is given in the text. The maps for $-65^\circ \leq \delta \leq +19^\circ$ are presented in order of increasing right ascension. A polar plot is given for $-90^\circ \leq \delta \leq -60^\circ$. Arrows on contour lines indicate directions of decreasing temperatures. (**To be seen in landscape**)



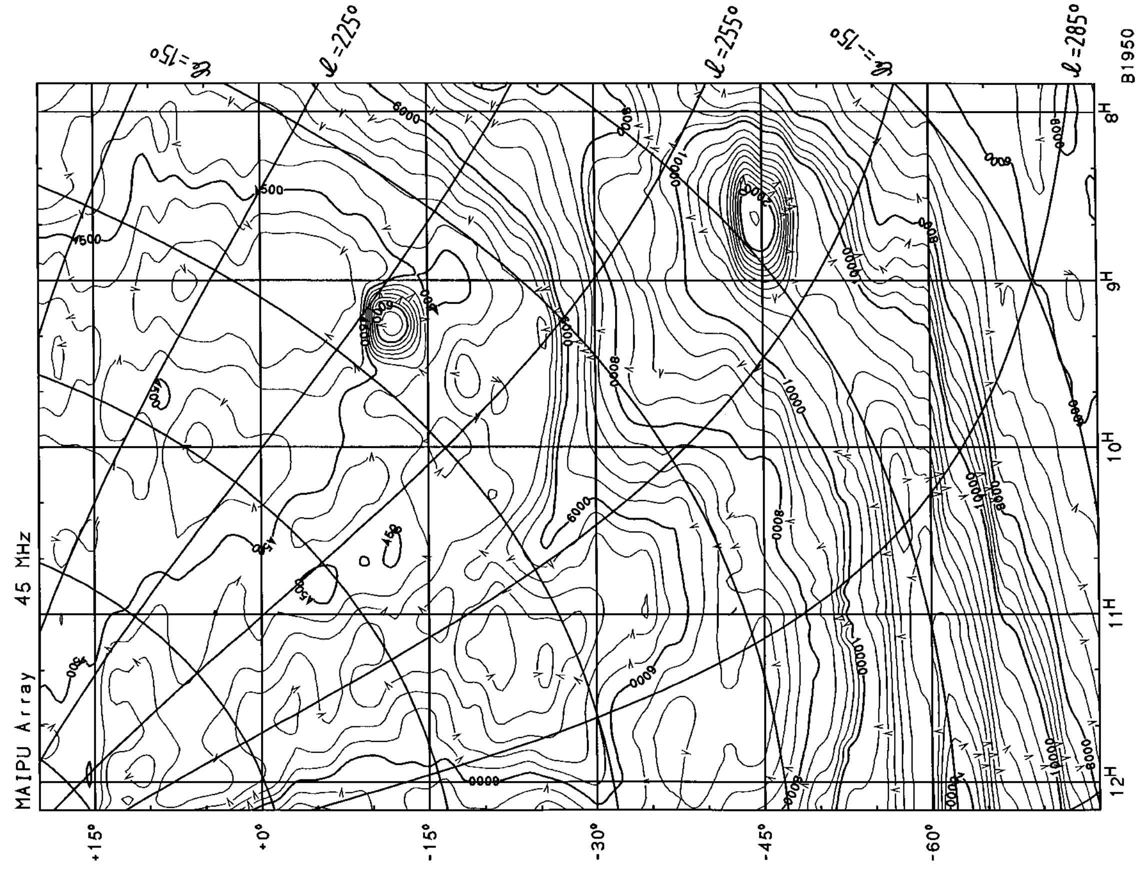
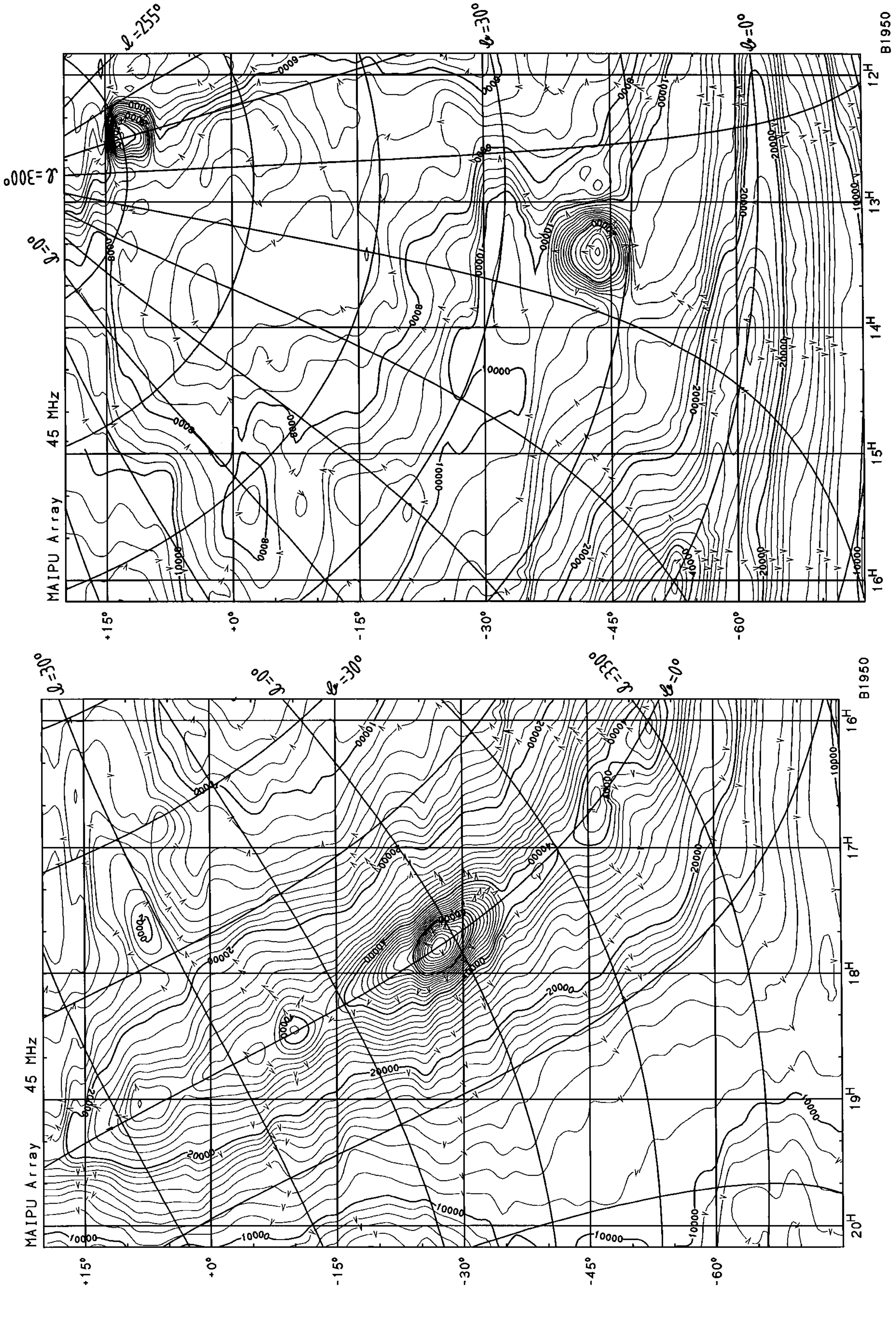


Fig. 1. continued. (**To be seen in landscape**)



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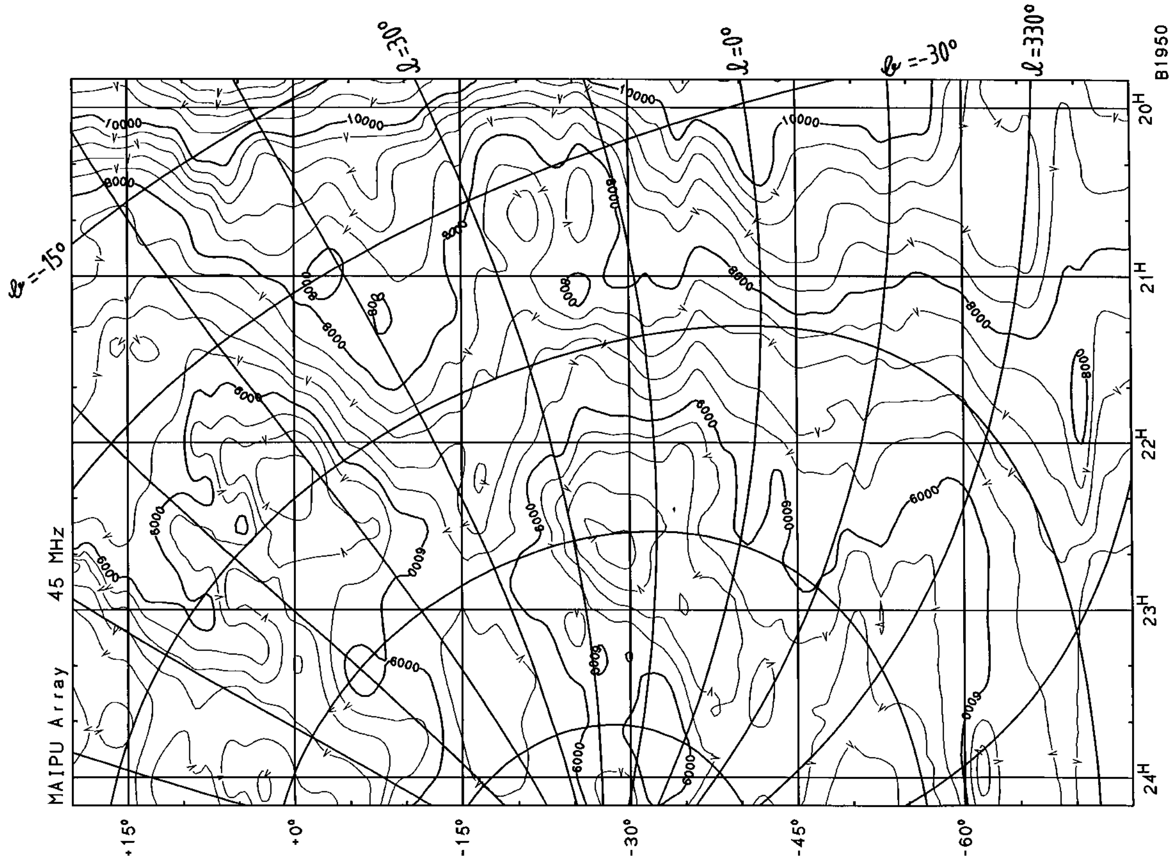


Fig. 1. continued. (**To be seen in landscape**)

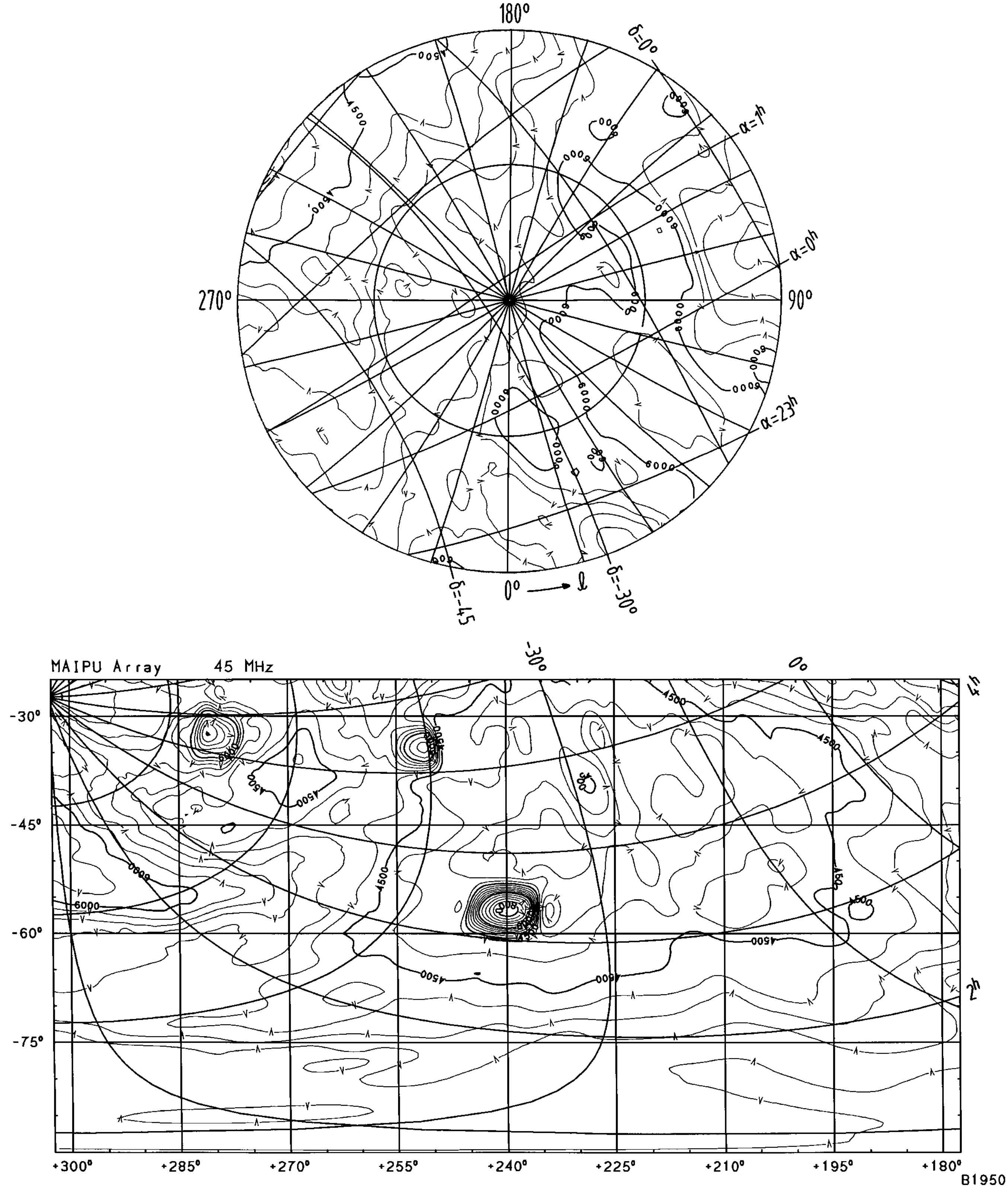
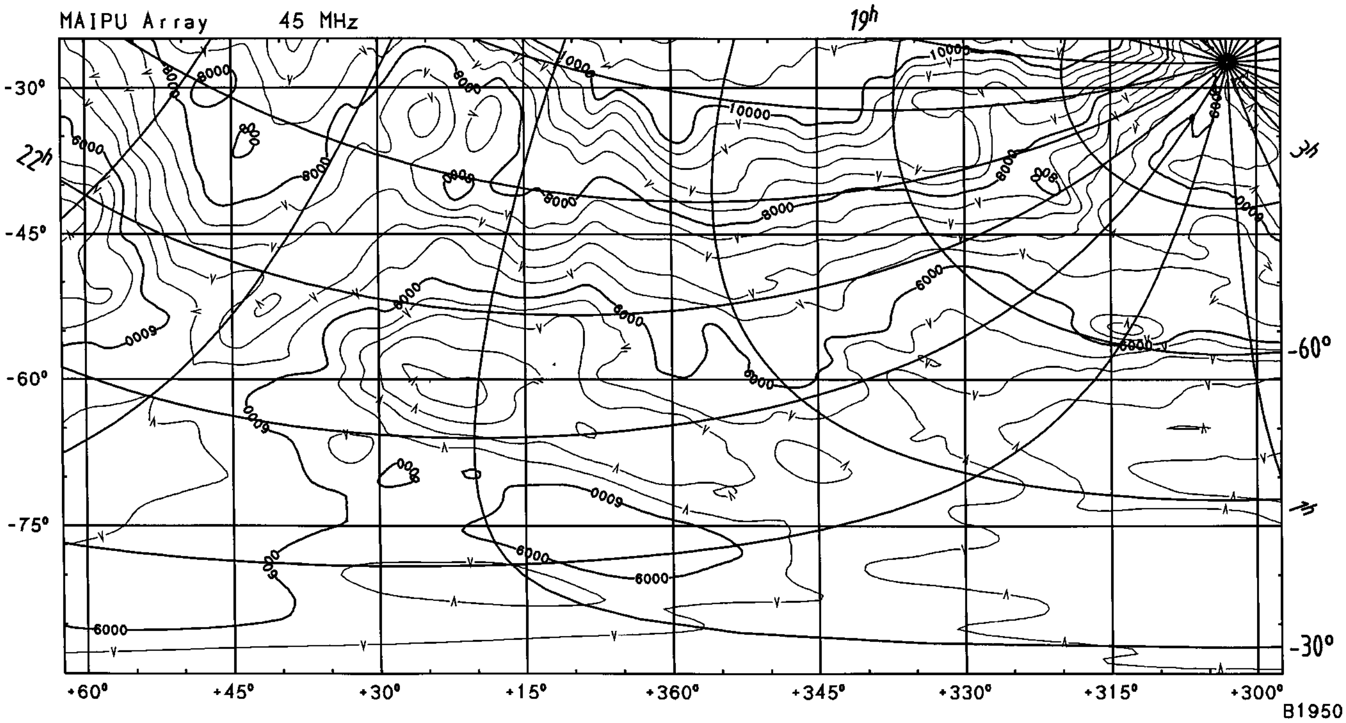
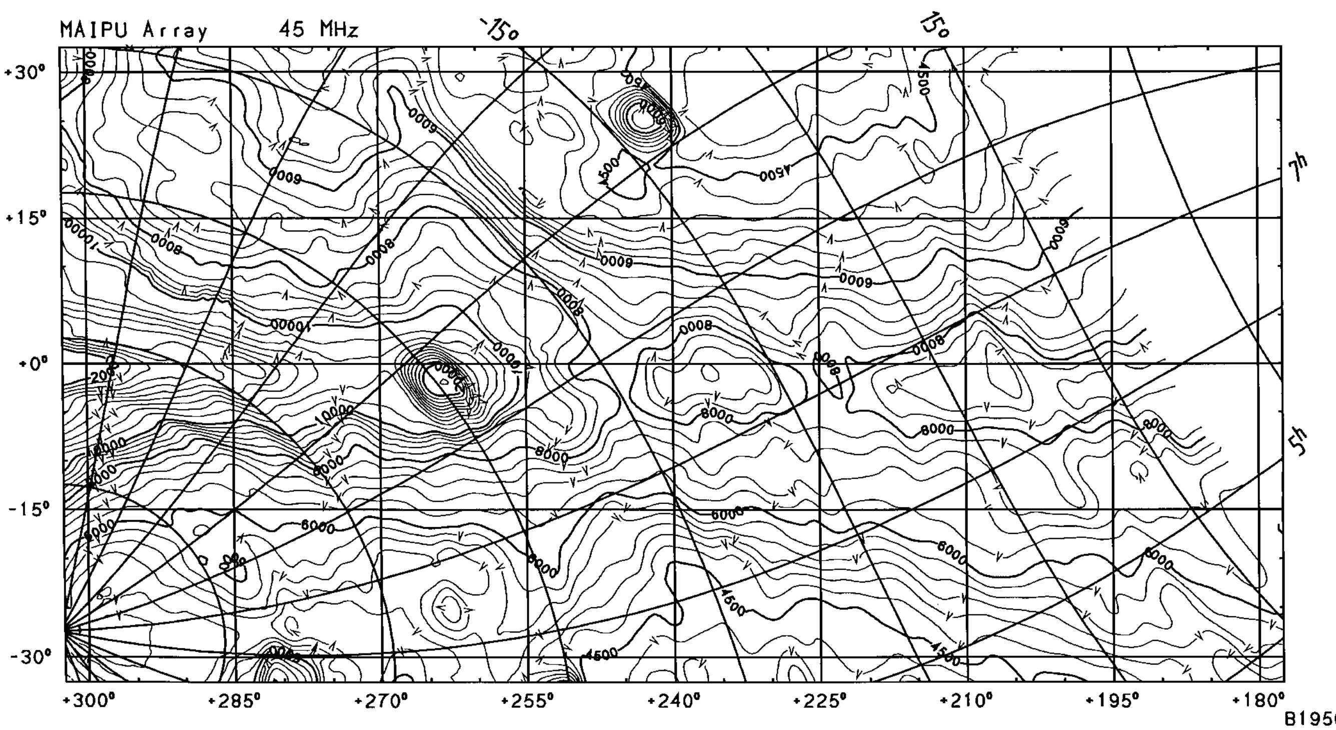


Fig. 2. Set of maps of the 45-MHz survey in galactic coordinates. Contour levels are the same as in Fig. 1 (see text). The maps are presented in the longitude ranges $300^\circ(-60^\circ) \leq l \leq 60^\circ$ and $180^\circ \leq l \leq 300^\circ$, and the latitude ranges $-90^\circ \leq b \leq -25^\circ$, $-30^\circ \leq b \leq 30^\circ$, and $25^\circ \leq b \leq 90^\circ$. Polar plots are given for $|\delta| \geq 60^\circ$





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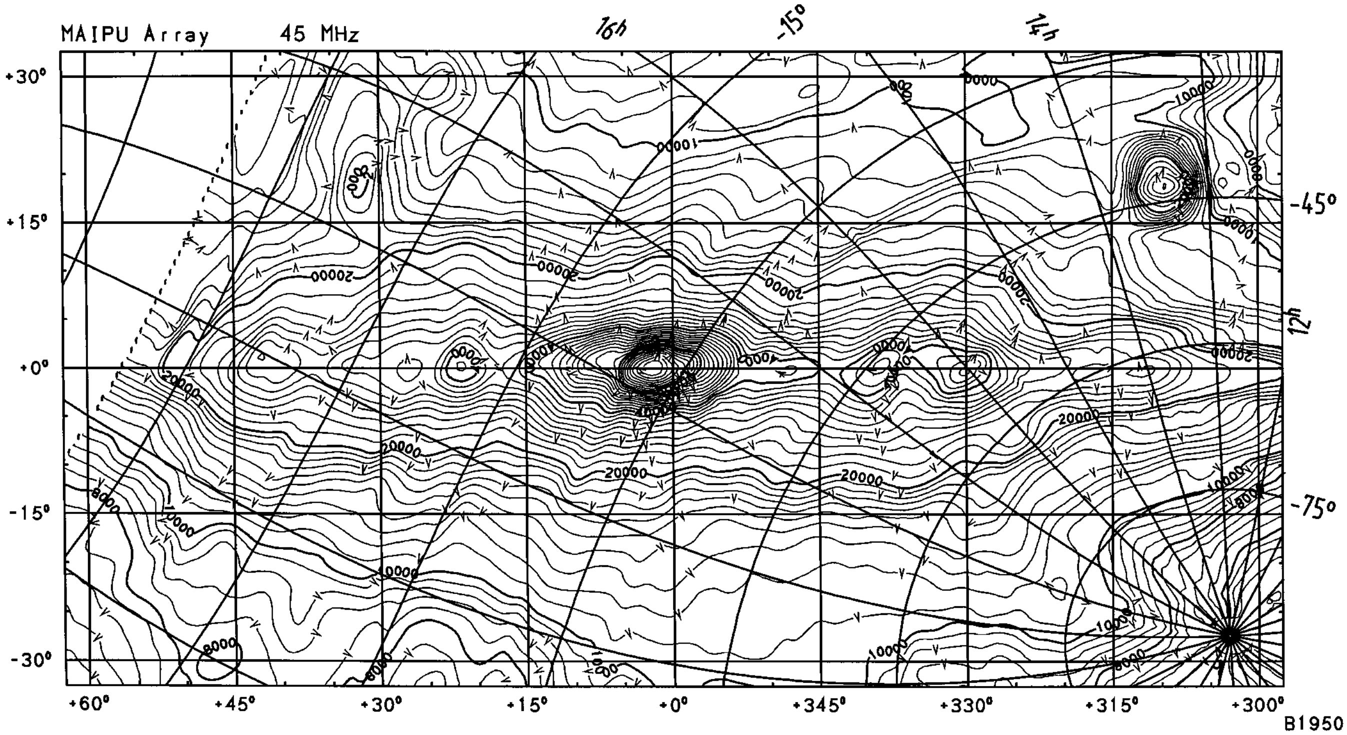

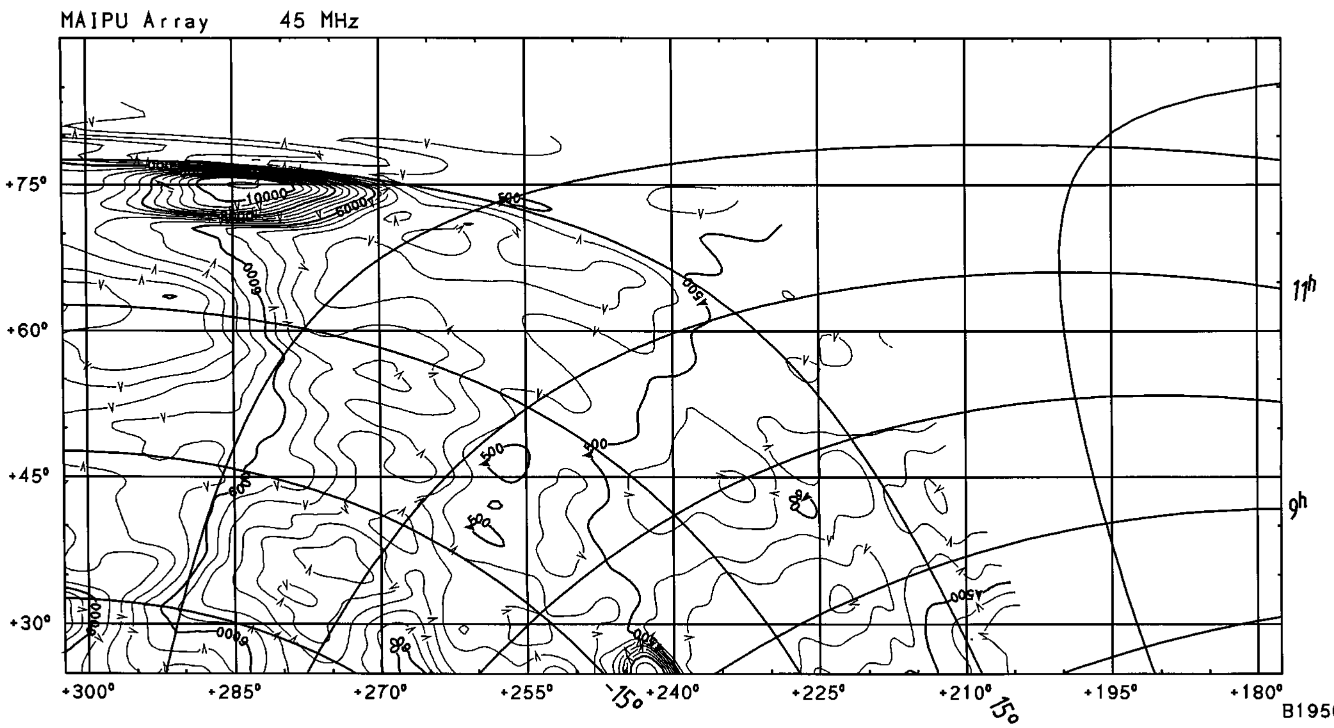

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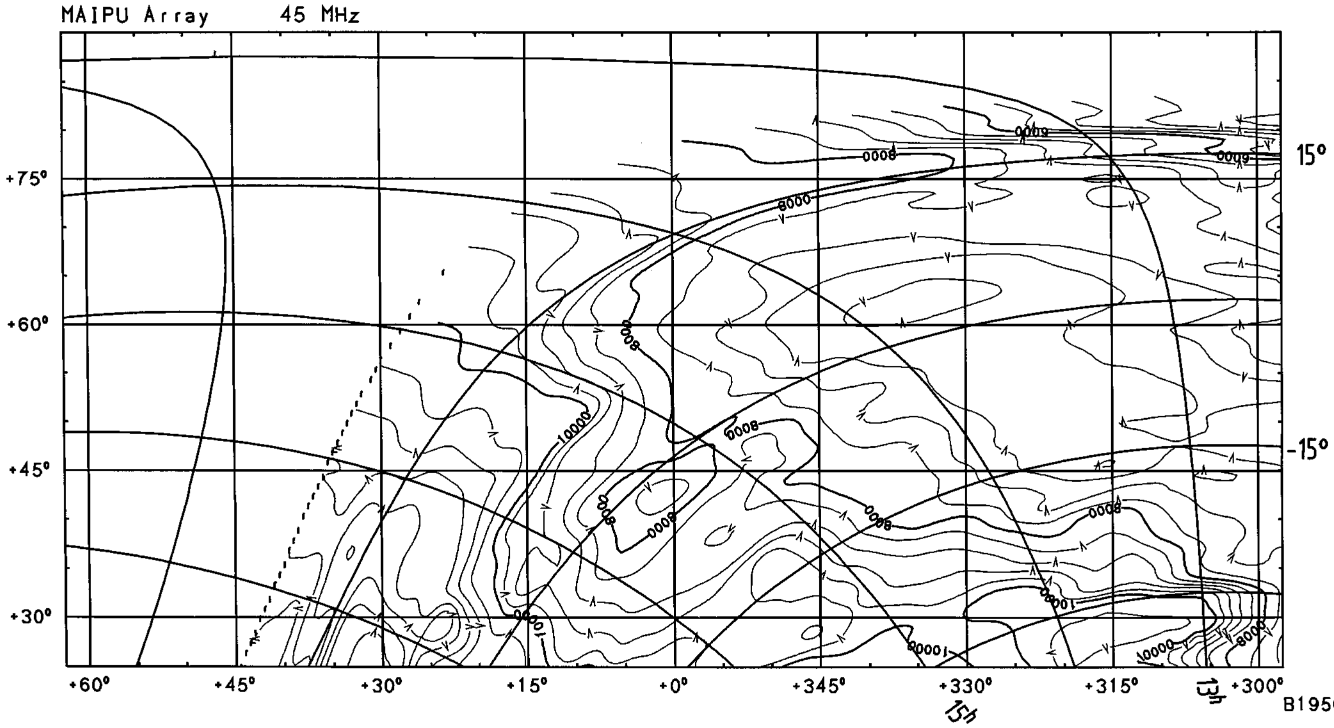

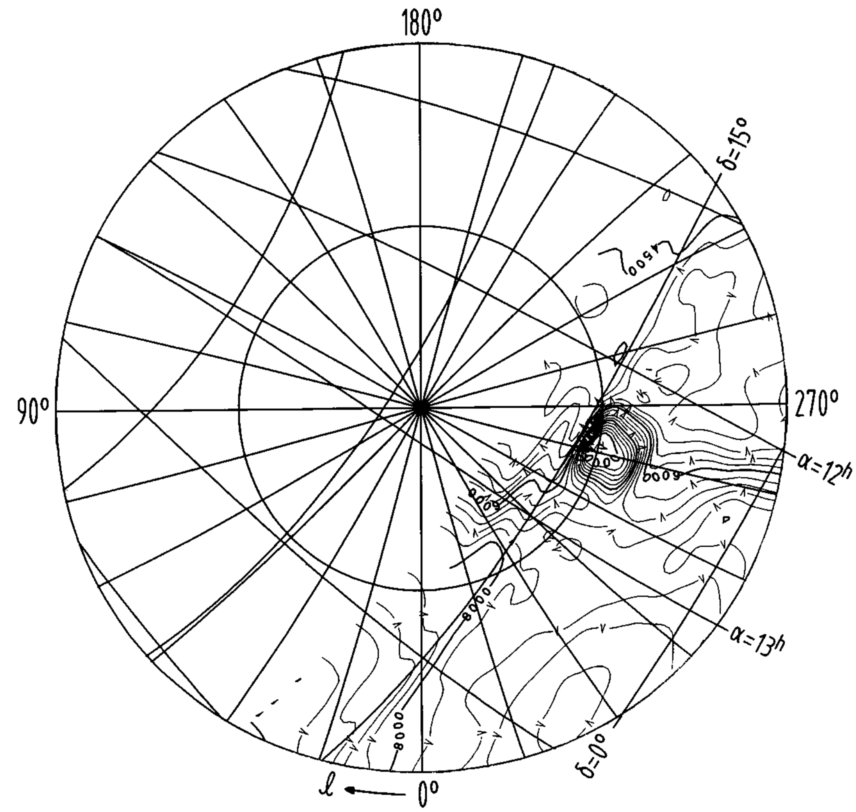

Fig. 2. continued

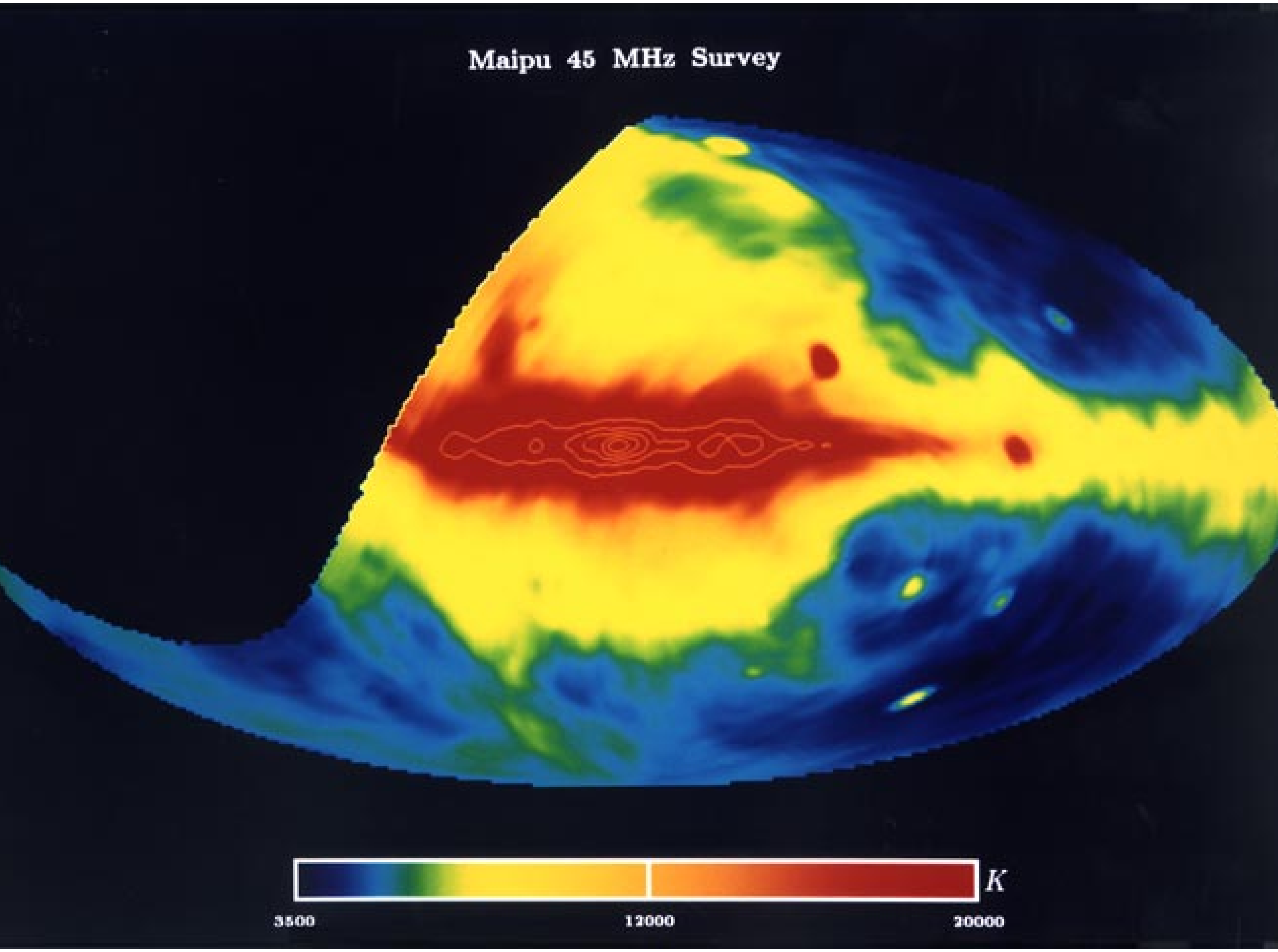

Fig. 4. 45-MHz survey in galactic coordinates in equal-area projection.

Figure 3 in A3 format, not available in the Online Version

Caption of the figure 3: Color coded map of the 45-MHz survey in galactic coordinates in equal-area projection. The code is shown in the figure. The contours begin at 30000 K and continue in steps of 10000 K

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