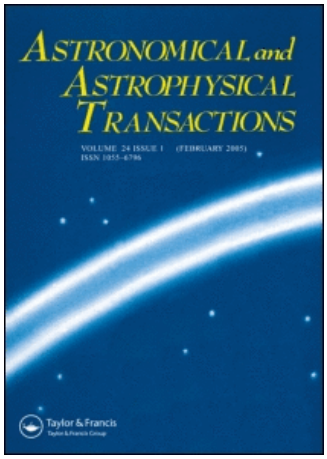

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S. A. Trushkin [a]
[a] Special Astrophysical Observatory Russian Academy of Sciences, Russia

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THE RATAN RADIO CONTINUUM SURVEY OF THE GALACTIC PLANE BETWEEN $l = 342°$ AND $l = 17°$ and $|b| < 5°$ AT 960 AND 3900 MHz

S. A. TRUSHKIN

Special Astrophysical Observatory Russian Academy of Sciences, N. Arkhyz, Russia, 357147

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The survey of the Galaxy in the direction to its center with the RATAN-600 radio telescope is discussed. The area of the survey is 0.11 sr. It is one third of the volume of the Galaxy in which supernova outbursts are possible. The perspectives of the survey, observations and data processing with a new computer program PRAT are discussed. The estimate of coordinate accuracy, on the basis of Bonn and Texas surveys, is shown to be better than 15″ in R.A. A full catalog of radio sources from well-known radio surveys is compiled. HII regions and planetary nebulae are selected from the compact sources of the IRAS survey, using well-known creteria. The table of measurements of flux densities and new estimates of spectral indices of 33 known supernova remnants in the survey region are given.

KEY WORDS Radio continuum, galactic survey, supernova remnants

1 INTRODUCTION

Galactic surveys in radio continuum have discovered more then 10000 radio sources in the Milky Way plane, but the galactic origin of only a small part of them was proved. Difficulty of the problem comes from the absence of both the source distance estimates and the optical identifications even for bright radio sources, and most of the sources have no spectral data at as many as 2–3 frequencies. As a result, hundreds of sources cannot be classified as thermal or non-thermal. Then the total number of supernova remnants (SNRs) in the Galaxy cannot be estimated, although centimeter radio waves are not absorbed when passing through the whole depth of the Galactic plane. Simple estimates show that the known sample of Galactic SNRs is full neither for weak and extended ($> 15'$) nor for bright and compact ($< 3'$) remnants. The number of detected flat-spectrum SNRs, plerions, is too small to be consistent with the SN rate in the Galaxy and the lifetime of 1000 years. It is difficult

to distinguish plerions from optically thin HII regions without special polarization measurements. Even conservative estimates give 300–1000 of SNRs in the Milky Way [1], while 170 SNRs have been identified in the radio range and 80 of them also in the optical range, and 50–80 in the IR and X-rays ranges. Owing to signiticant extinction in other wavelangth ranges, radio waves are the most promising for the search for SNRs. Galactic surveys with Parkes and Effelsberg telescopes [2, 3] indicate that surveys at one-three frequencies at moderate resolution ($\sim 1'$) are more fruitful for the search for new SNRs at both extremes of the distribution of SNRs over size and brightness [4]. This search for new SNRs is the main objective in the survey of the Galaxy with the RATAN-600 radio telescope.

2 OBSERVATIONS AND DATA PROCESSING

The two-frequency radio survey of the Galactic plane was performed at 960 and 3900 MHz with the RATAN-600 radio telescope in two sets: in 1991–92, the region: $342° < l < 360°$ and $|b| < 5°$ and in 1993–94, the region $342° < l < 17°$ and $|b| < 5.5°$. The 3900 MHz radiometer has a HEMT preamplifier, cooled down to 12 K with a closed cryogenic system. The 960 MHz radiometer is based on a low-noise, non-cooled wide-band transistor amplifier. In the latter set, another frequency 11 GHz was added with the noise level at about 20 mJy/beam, for the beam size of $25'' \times 14''$. This radiometer is also cooled by a closed cryogenic system. The resolution (HPBW, RA*DEC) is $4' \times 75'$ and $1' \times 39'$, the noise level is typically 60 mJy/beam and 10 mJy/beam at 960 and 3900 MHz, respectively. The step of scans (cross-cuts) is $20'$ in declination, as constrained by the half of the vertical HPBW at 3900 MHz for the "North sector" antenna of the RATAN-600 radio telescope. Repeating the survey in other epoch will allow to distinguish variable sources in the Galactic plane, in order to detect galactic binary systems such as SS433 and Cyg X-3, and very young (< 100 years) supernova remnants. It is very important because the same program was carried out only for the first quadrant [5].

The observations was carried out in the meridian transit of the fixed beam of the antenna through the Galactic plane. The calibration of day-to-day changes in gain pointing was provided by observations of the sources PKS 0237-23, 3C161, PKS1830-21 and some sources from the list of Ref. [6], for which flux densities were accepted in accordance with Baars's scale [7]. The data of the survey are in the form of about 250 f-files [8] at each frequency, or$\sim 250^h$ of observations. The area of the survey is more than 350 deg^2 or ≈ 0.11 sr (Figure 1) Each cross-cut was repeated 2–5 times in order to minimize atmospheric fluctuations. The survey has the flux sensitivity of about 50 and 10 mJy/beam or 40 and 5 mK/beam in brightness temperature at 960 and 3900 MHz, respectively. Observations at 11 GHz were aimed at strong sources.

It should be noted that all the SNRs known earlier were seen in the RATAN-600 observations with high signal-to-noise ratio; they will be discussed elsewhere. Here we give only a summary table of flux density measurements for the SNRs from the new Green's catalog [9]. In many cases the more accurate determination of the

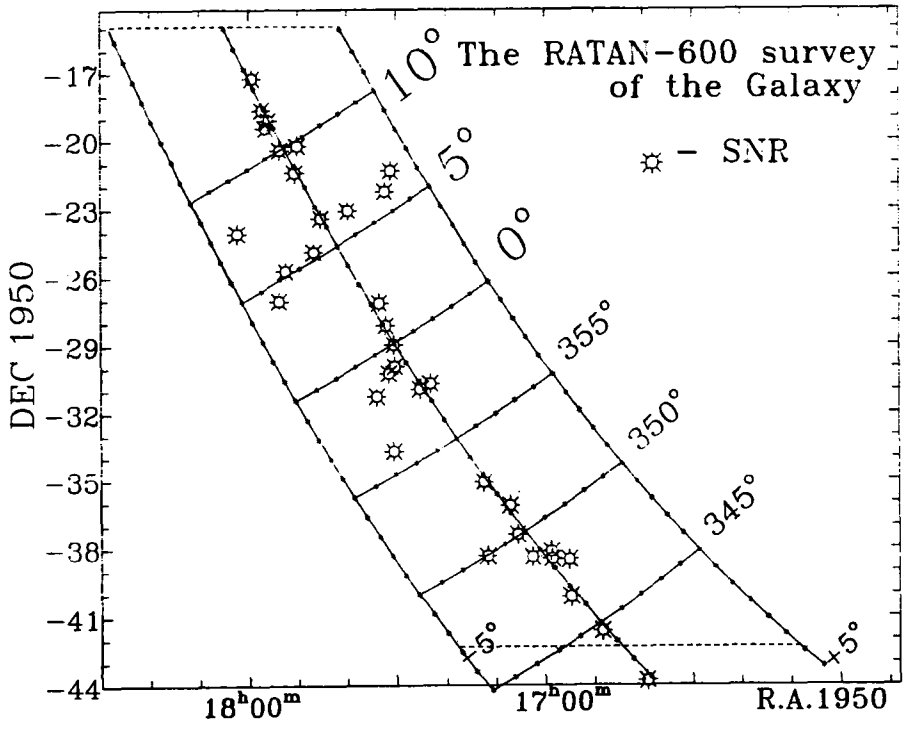

Figure 1 The survey region in equatorial coordinates. The known SNRs are marked by asterisks.

spectral index makes doubtful the identification of the source as a SNR (Table 1). Table 1 contains: galactic coordinates of the SNR in column (1); columns (2) and (3) give right ascension and declination (B1950); column (4), the angular size of remnant: MAX × MIN and the new measured size in parentheses; (5) and (6), the measured flux densities at 2.7 and 7.6 cm wavelengths; (7) shows the measured flux densities at 960 MHz and estimated values at 1000 MHz from Green's catalog; in column (8) the "old" spectral indices from Green's Table 1 and "new" ones ($S \sim \nu^{-\alpha}$) deduced from available and measured integrated flux densities are given. All the flux measurements are in the same Baars's flux scale. The sign "?" means poor data or large uncertainty. The sign "var" means variability.

A new system PRAT of data-processing for the *f*-files obtained, adapted for galactic scans and extended sources, was developed under MS DOS. This interactive program, based on older packets PRF/IRF for the minicomputer SM1420 [10], was first written by T. Sokolova and S. Trushkin in 1991–92. We used new procedures of subtracting the Galactic background, based on spline approximations, temperature/flux calibrations and removing of interferences by means of the Hodges–Lehmann smoothing [11]. The code was compiled in MS C7.00 with standard libraries. The code works with any graphics monitor. The size of the executab-

Table 1. The flux densities of SNRs measured in the survey Galaxy

RATAN-600 *l b* (1)	*RA(1950)* *hh mm ss* (2)	*DEC* *dd mm* (3)	*Size* *arcmin* (4)	*Flux* *2.7 cm* (5)	*Densities* *7.6 cm* (6)	*(Jy)* *31cm/1GHz* (7)	*Index (α)* *old/new* (8)
0.9 +0.1	17 44 12	−28 08	8(6.6)		9.3	/18?	var /.26
1.9 +0.3	17 45 37	−27 09	1.2	0.15	0.45	/0.6	0.7 /.62
4.2 −3.5	18 05 45	−27 04	(28)		5.4	3.2/3.2?	0.6?/0.0
4.5 +6.8	17 27 43	−21 27	3		8.3	21/19.	0.64/.63
5.2 −2.6	18 04 25	−25 45	(18)		1.8	1.0/2.6	0.6?/0.0
5.4 −1.2	17 59 00	−24 50	35		21.	33/35.	0.2?/
5.9 +3.1	17 44 20	−22 15	20		1.6	2.6/3.3?	0.4 /.36
6.4 +4.0	17 42 10	−21 20	31		0.9	1.5/1.3?	0.4 /.37
7.7 −3.7	18 14 20	−24 05	(18)		6.7	11.8/10	0.32/.35
8.7 −5.0	18 21 05	−23 50	(26)		4.4	8.9/4.4	0.3 /.50
8.7 −0.1	18 02 35	−21 25	(45)		63.	95/90	0.25/.28
9.8 +0.6	18 02 10	−20 14	12		1.9	4.1/3.9	0.5 /.52
10.0 −0.3	18 05 40	−20 26	8? (5.7)		3.3	4.7/2.9	0.8 /.7
11.2 −0.3	18 08 30	−19 26	4 (4.7)		9.6	17./22	0.49/.46
11.4 −0.1	18 07 50	−19 06	8		1.7	/6	0.5 /.50
12.0 −0.1	18 09 15	−18 38	5? (2.4)E	.15	0.4	2.7/3.5	0.7 /1.0
	18 08 55	−18 38	(1.)W	1.73	2.1	2.4/	/.12
13.5 +0.2	18 11 20	−17 13	(5 x 4)		1.8	/3.5?	1.0?/0.5
15.1 −1.6	18 21 05	−16 36	(30 x 24)		3.9	4.8/5.5?	0.8?/0.2
15.9 +0.2	18 16 00	−15 03	7 x 5(5.1)	1.05	1.9	4.0/4.5	0.7?/.62
16.7 +0.1	18 18 07	−14 22	3	1.05	2.1	3.8/3.5	0.7 /.39
344.7 −0.1	17 00 20	−41 38	8? (8.3)		1.4	3.6/3.5	0.4?/.53
346.6 −0.2	17 06 50	−40 07	8(10.2)	2.9	6.3	11.4/10	0.5 /.45
348.5 +0.1	17 10 40	−38 29	10(10.8)		41.	118/72	0.3 /.46
348.7 +0.3	17 10 30	−38 08	10(8?)		21.	/26	0.3 /.29
349.7 +0.2	17 14 35	−37 23	2.5 x 2	4.0	8.4–11.4	25/20	0.5 /.42
350.0 −1.8	17 23 40	−38 20	30(44)		9.2	15/31	0.5 /.50
350.1 −0.3	17 17 40	−37 24	4? (6.4)		2.1	6.2/5.6	0.7 /.84
351.2 +0.1	17 19 05	−36 08	6 x 4(6.5)	2.7	2.6	3.3/5.8	0.4 /.24
352.7 −0.1	17 24 20	−35 05	6 x 5(6.3)	1.4	2.6	/6?	0.6?/.58
355.9 −2.5	17 42 35	−33 42	13(15)		4.0	7.6/8	0.5 /.50
357.7 −0.1	17 37 15	−30 56	12 x 6(16)	8.6	25/19	43/37	0.4 /.48
357.7 +0.5	17 35 20	−30 42	24(27)		6.1	7.2/10	0.4?/.15
359.1 −0.5	17 42 20	−29 56	24(29)		15.5?	/14	0.4?/0.0

le file is 200 Kbytes and now the code is being adapted to X-windows and Linux system.

In Figure 2 the same cross-cuts of the survey on DEC 21°40′ are shown at three wavelengths in the form of the PRAT output. The compact HII region 1800–217 and the remnant of SN1604 (Kepler's SN) 1727–215, the latest of the optically visible SNRs for the last 400 years are visible.

Finally, coordinate and flux calibration was performed using PRAT for all the cross-custs of the survey. By comparing right ascensions of 60 point sources from the Bonn [3] and our survey, it can be shown that the error (rms) in R.A. is equal to 30″, with errors of the Bonn coordinates (R.A.) being about 20–35″. This comparison was made for all 134 sources from the Texas (TP) survey with S_V(365 MHz) >

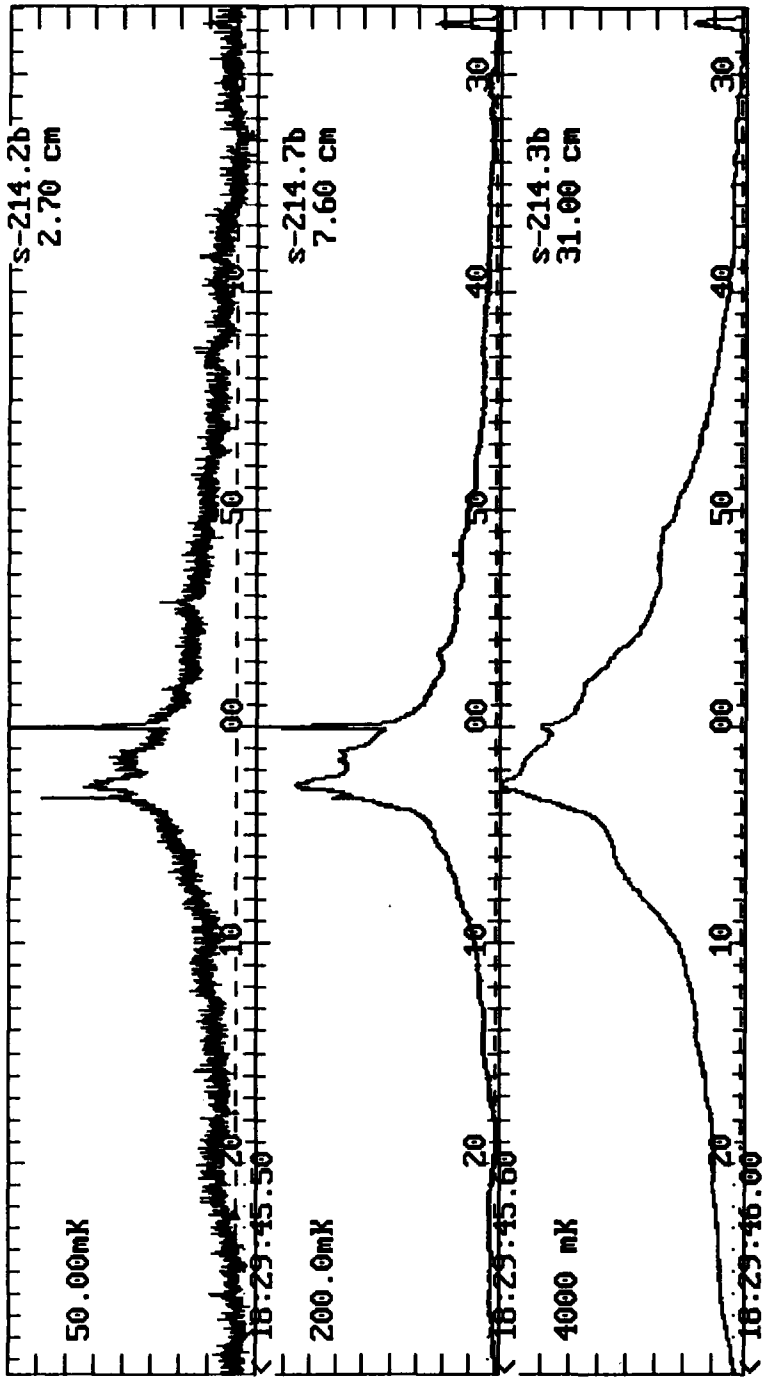

Figure 2 The survey cross-cut of Galaxy (Dec = $-21°40'$, $|b| < 5°$) at three frequencies. Bright thermal sources and extended galactic background can be easily seen in these scans.

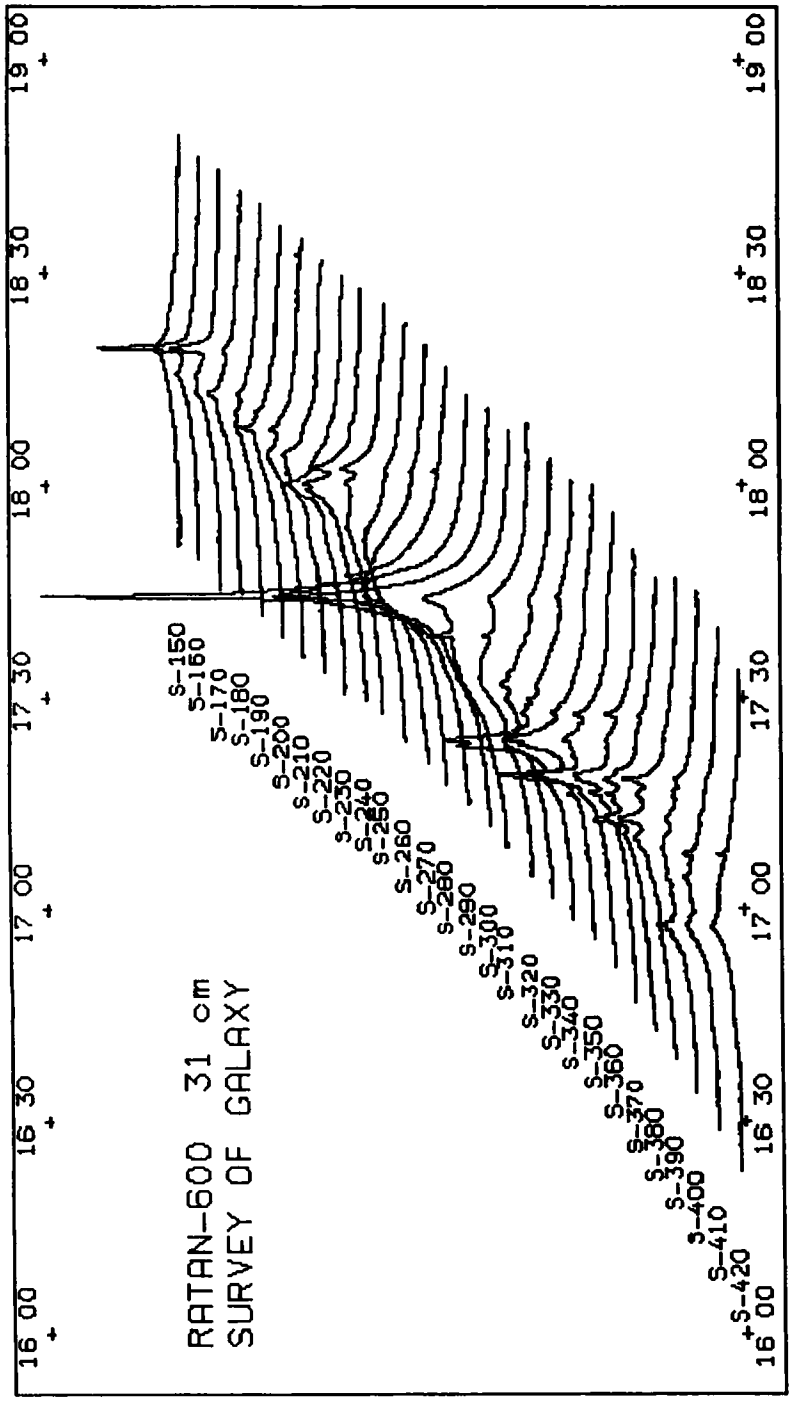

Figure 3 The survey cross-cuts in the same scale at 960 MHz. The step is 1° in the region $-42° \div -15°$. The center of Galaxy is the brightest source in the survey.

800 mJy. For 30 point TP-sources the same coordinate error is 19″. For other sources the shifts are up to $\geq 50''$, characteristic for the error of the lobes of the Texas interferometer. It should be noted that this radio telescope shows large shifts in coordinates just for extended sources. Thus, the accuracy of the R.A. determinations is better than 15″. The errors of determination of declinations depends on many factors, but for compact sources brighter than 300 mJy it is 3–5′. Now a catalog of *f*-files at 3900 and 960 MHz, cleaned from impulse and atmospheric interferences, is available.

In Figure 3 scans of the survey at 960 MHz between Dec. −42° up to −15° through 1° are shown. The dynamic range is small because of the brightest source at center of the Galaxy. The real dynamic range is as large as 10000.

3 FORMING A CATALOG OF KNOWN SOURCES

We used the new data base of astronomical catalogs [12] to compile a catalog of radio sources in the area of the survey. The data base includes the sources of the Texas, Parkes, Molonglo, Master, List, Effelsberg, Nobeyama and VLA surveys. This catalog consists of more than 1500 source inputs including electronic versions of the galactic catalogs [13–16]. This is an important point in studies of the sources detected in the survey. We can determine new variable sources, and in order to indicate thermal sources in the survey region, all HII regions and planetary nebulae (PN) from the IRAS point sources catalog (IPSC) were selected using special criteria [17]. The whole catalog consists of 2295 HII regions and 995 PNs. We prepared a modification of the IPSC electronic version suitable for using the data base.

4 DISCUSSION

The high sensitivity in brightness temperature gives a possibility to detect new weak extended sources, especially old SNRs. Some problems of the SNR detection was discussed in Refs. [14, 18–21]. New Galactic VLA-surveys discovered hundreds of new compact sources which were identified with the Galactic population [22–27]. The Molonglo survey [28] revealed abundance of a galactic thermal sources. The IRAS data are actively used for identifications of non-thermal galactic sources [29]. We plan to compare the ISSA map of the IRAS survey and our radio scans in order to separate these sources from thermal HII regions and PNs. Young SNRs and old radio supernovae were searched for in a list of 290 compact ($< 2'$) radio sources [30]. But this set of VLA observations revealed only one SNR candidate younger than 100 years and some SNRs candidates older than 300 years. The low efficiency of this search is explained by the fact that only 10% of the 3–4 SNs in the Galaxy exploded in the last century could be detected in this study. In any case, further searches should be concentrated on sources with $S_{1\mathrm{GHz}} = 0.3$–1.5 Jy. New 1.4 GHz NRAO VLA sky survey will be especially efficient in the search for weak young SNRs in the

Galactic plane [31]. It should be also noted that the region of the survey includes about 30% of the whole part of the Galaxy where supernova explosions are possible. In radio continuum, only the size and variability could help to distinguish SNs from background extragalactic radio sources, therefore only SNRs older than 50 years could be detected in our survey. About 2000 radio sources should be considered in order to detect a young SN with probability of order unity.

The lower limit on the number of detected sources in the final catalog should be no less than 2000. Detailed studies of detected radio sources will give us understanding of their nature.

Our results allowes to estimate the flux density of the X-nova GRO J1650–40 long before its identification at radio wavelengths [32]. In the epoch 1991.2, its flux was equal to 100 ± 10 mJy at 3900 MHz. Some details of the survey were discussed in [33].

5 CONCLUSIONS

Identifications, comparison and spectral index studies have been made with the source of the Effelsberg, Nobeyama, VLA and Texas radio surveys and of the IRAS catalog. A search for supernova remnants and variable radio sources was made. Thermal sources, planetary nebulae and H II regions were revealed, and a new combined ISSA map of the IRAS all-sky survey will be used now for a search for new SNRs. Bright regions of the Milky Way were also observed at 11 GHz. Now the survey data are being processed in order to obtain a catalog of the sources including the coordinates, flux densities at 2–3 frequencies and possibly spectral indices. For $\sim$ 150 sources the errors in R.A. are less than 15″ as obtained from comparing with the sources of the Bonn and Texas surveys. Using 2–3 frequencies allows in many cases to avoid confusions and ambiguities in the determination of extended sources against Galactic background. The background itself can be a subject of intensity and spatial distribution studies.

I would like to thank the technical services of RATAN-600 for providing a possibility to carry out difficult and prolonged observations in the semi-automatic regime of the antenna. I am grateful to my colleagues T. N. Sokolova and O. V. Verkhodanov for help in using their new methods of data processing, and to V. A. Lebedev and Dr. H. Andernach who kindly presented electronic versions of astronomical catalogs.

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