A 10 GHz RADIO CONTNUUM SURVEY OF THE GALACTIC PLANE REGION.II

- The galactic center region 4°x4° -

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ABSTRACT

This is the second paper of a series representing the results of a 10 GHz radio continuum survey of the galactic plane region. We report here about a large area (4°x4°) mapping of the galactic center region at 10.55 GHz with a HPBW=2.6'. The maps reveal a prominent off-plane radio lobe of diameter 1x1.2° centered on l=359°.7, b=0°.6 extending towards positive galactic latitude. The lobe has a flat spectrum, indicating a thermal gas origin. The lobe may be an evidence for an explosion or a channelled exhaust of matter from the galactic nucleus. We report also a discovery of two new supernova remnants of shell type located at G359.1-0.5 and G359.0-0.9.

Key Words : Galactic center; Activity ; Radio continuum ; supernova remnant.

1. Introduction

Current studies of radio continuum esmision from the neclear region of the Galaxy have been concentrated mainly to regions close to the galactic plane. Thermal emission from extended HII regions near the galactic center has been extensively studied by Mezger and Pauls (1979). However, no systematic research has been made of off-plane, more diffuse radio emission, which is characterized by many radio ridges and spurs emerging from the galactic plane toward higher galactic latitudes. In this paper we represent a large area (4°x4°) and high resolution (HPBW=2.6') maps of the galactic center region at 10.55 GHz with a large dynamic range. We describe prominent off-plane radio structures and discuss their physical characteristics.

This paper is the second of a series representig results of a 10 GHz radio continuum survey being carried out at the Nobeyama Radio Observatory using the 45-m radio telescope. A part of the survey work has been reported by Sofue et al (1983 ; 1984), and a brief report about a discovery of a large diameter radio lobe likely related to the galactic nucleus activity has been given by Sofue and Handa (1984).

2. Observations

The observations were made on April 25, 1983 using the 45-m radio telescope at the Nobeyama Radio Observatory. The HPBW of the 45-m dish was 2.57±0.03' at the center frequency of 10.55GHz. The first side lobe level was below -20 dB, which provided a high dynamic range measurment of such a region involving strong radio sources like as the galactic center. We used a cooled parametric amplifier combined with a Dicke-switching system referring a cooled dummy load at 20 K stage. The bandwidth was 500 MHz and the system noise temperature was approximately 100 K. We used a circularly polarized feed system and detected one polarization component. Total intensity was obtained by assuming that circualr polarization of the sources is neglibigle. The flux densities were calibrated using a reference noise source which was calibrated by the radio sources 3C123, 147 and 348, whose fluxes were taken from Tabara et al. (1984). The conversion factor between the brightness temperature and equivalent flux density per beam area was taken as $T_b/S = 0.47 \pm 0.05$ K/Jy.

We mapped a squared area of 4°x4° centered on the galactic center at RA(1950)=17h 42m 29.29s, Dec (1950)=-28° 59' 17."6. The area was scanned in the direction perpendicular to the galactic plane with the spacing of 1.2' at a speed of 4°/50 sec. Total observing time was about 3.5 hours and the effective integration time per beam area was 1.4 sec. The two extreme sides of each scan at b= ±2° were taken to be zero levels.

The data reduction was made using the radio astronomical reduction system at the NRO, a part of which contains the NOD2 reduction package described by Haslam (1974). Scanning effects, which are mainly caused by weather condition, were removed by using the "pressing" method of Sofue and Reich (1979). The computations were made on a FACOM M200 at NRO.

3. Results

Figure 1 shows a 10 GHz continuum map of the whole observed region of 4°x4° centered on the galctic center,where the map is smoothed to a gaussian beam of HPBW=3.'6. Figure 2 shows detailed maps of the region devided into 1°.1x1°.1 areas with the original resultion of HPBW=2'.6. The unit of the numbers on contours in both figures represents surface brightness in 4.0 mK T_b, or equivalently 8.65 mJy/2'.6 beam area ($1.36 \times 10^{-22} W\ m^{-2} Hz^{-1} str^{-1}$). The rms noise in the map calculated for a quiet region is about 20 mK in T_b. The figure reveals a number of strong discrete sources including the Sgr A and B . The majority of the sources are located near the galactic plane and have been discussed so far by many authors. Below we give a source list of the region and discuss off-plane, extended features found in the map.

Fig.1

(i) Source list: Table 1 gives the list of sources detected in the mapped area. The sources were picked up by applying a two dimensional gaussian fitting program, which detects relatively compact sources with clear peak enhancements. Very extended sources with scale sizes greater than several HPBW are not completely picked up. Below are instructions to the table .

Column 1: Galactic longitude

Column 2: Galactic latitude

Column 3: Peak flux density at 10.55 GHz, S_p

Column 4: Half maximum gaussian width of the apparent extension of the source in the longitude direction, θ_l

Column 5: Half maximum gaussian width in the latitude direction, θ_b

Column 6: Total flux density calculated through $S_t = S_p \theta_l \theta_b / HPBW^2$

Column 7: Remarks.

Columns 1 through 5 give also mean errors to the calculated quantities.

Table 1

(ii) Two new supernova remnants:

In figure 1 we find two loop (arc) -shaped sources. A loop of diameter about 21'is seen centered on (l,b)=(359°.1,-0°.5), which we call hereafter as G359.1-0.5. The other is an arc at (l,b)=(359°.2,-0°.9). If we fit this arc with a loop, its center is at around (l,b)=(359°.0, -0°.9) with a diameter of about 23'. We call this source as G359.0-0.9. These two sources are recognized on the 5 GHz maps of the Bonn and Parkes surveys (Altenhoff et al.1978; Haynes 1980). Figure 3 is a close up of the two SNR at 10 GHz to see their loop structures more clearly, where the background filtering (BGF) method (Sofue and Reich 1979) has been applied so that large-scale smooth background structures have been removed.

Fig 3

From a comparison of the brightness at 5 and 10 GHz both sources are nonthermal: The spectral index of the brightest ridge of G359.1-0.5 is $\alpha \approx -0.6$, and that of G359.0-0.9 is $\alpha \approx -1.0$. Judging from the shapes and spectral indices, we may conclude that the two sources are supernova remnants of shell type,which have been not catalogued on any existing list of SNRs. The total flux density of G359.1-0.5 is calculated to be S=5.1 ±1 Jy at 10GHz , and that for G359.0-0.9,S=11 ± 2 Jy. The observed quantities are summarized in Table2, where are also listed derived parameters as the linear diameters, distances, ages and expansion velocities. Here we assumed spectral index for the whole G359.1-0.5 as $\alpha \approx -0.6$ and for G359.0-0.9 as $\alpha \approx -1.0$. A Σ-D relation of Clark and Caswell (1979) at 5 GHz was used to derive the diameters. A sedov's (1959)similarity solution was applied to derive the age and expansion velocity by taking the initial explosion energy of 10^{51} ergs and ambient gas density of n_o=1 H atom cm^{-3}.

Table 2

(iii) An omega-shaped Radio Lobe

Many ridge-like radio spurs emerge from the galactic plane and extend toward higher latitudes. Among them two spurs at (l,b)=(0.2°, 0.2~1°) and at (-0.6°, 0.1~1°) are the most prominent structures in the off-plane radio emission near the galactic center (figure 1).We note that both spurs are bending toward the galactic center direction: they are convex with respect to the galactic nucleus. We emphasize that the two ridges are connected with a radio arc at b=1.2°: the two spurs compose both sides of a giant

Ω - shaped radio loop , which we call hereafter as the Galactic Center Lobe (GCL) . The geometrical center of the lobe is approximatley (l,b)= (359°.7,0°.6). Its angular diameter in the longitude direction is approximatley 1.1°, which corresponds to a linear diameter of D=185 pc at a 10 kpc distance. The height of the lobe is about 1.2° from the galactic plane, or about 210 pc.

Physical properties and possible origin of the GCL have been discussed by Sofue and Handa (1984). The total flux density of the lobe integrated at b ≥0.2°, after subtraction of the background smooth component, is about 132 ± 10 Jy at 10 GHz. The spectrum between 5 and 10 GHz is as flat as α= -0.1. The flat spectrum indicates either its thermal gas origin or synchrotron origin with energetic cosimc ray electrons continuously injected from the galactic nucleus. Table 3 summarizes the derived parameters when the GCL is assumed to be composed of thermal gas. Possible formation mechanisms have been suggested by Sofue and Handa (1984): (a) an explosion or a channelled exhaust of matter due to the galactic nucleus activity :(b) inflation of a loop of magnetic tube from the nuclear disk with cosmic rays and thermal gas by a Parker type instability as in the case of a solar loop prominence.

Table 3

Similar off-plane radio lobes and jet structures have been observed in central regions of several edge-on galaxies. Hummel et al (1983) have shown that the edge-on galaxies NGC2292, 3079, 4388, 4438 and 6500 have radio jets which extend from the nuclear regions almost perpendicularly to the galactic plane. Duric et al. (1983) have shown that NGC3079 has a radio loop extending from the galaxy center. They suggest that such an off-plane radio lobe may be a result of an inflation of magnetic bubble from the nuclear disk of the galaxy. It is likely that the presently found omega-shaped radio lobe in our Galaxy is a similar phenomenon to the above mentioned radio lobes and jets in edge-on galaxies, although the scales are much different: the scale of the GCL is about 200 pc, while the jets in the edge-on galaxies are about 1 to 3 kpc. We suggest that a channelled exhaust of energetic materials from nuclear regions, more or less of various scales, is a common phenomenon in spiral galaxies including our own Galaxy.

4. Concluding Remarks

We have represented a large area (4x4°) radio continuum maps at 10.55 GHz of the galactic center region with a 2.6' HPBW resolution. The maps reveal a number of interesting features extending toward high galactic latitudes. Among them the most interesting objects are the two prominent spurs composing a loop or a lobe over the galactic center, which we call as the galactic center lobe (GCL). The spectral index of the lobe is as flat as α =-0.1 which suggests its thermal gas origin. The lobe may be an evidence for an explosion or a channelled exhaust of matter at the galactic nucleus. An inflation of magnetic tube filled with gas and cosmic rays from the magnetized nuclear disk may be an alternative possible origin for such a lobe structure. We have also found two new supernova remnants of shell type, G359.0-0.9 and G359.1-0.5. Derived parameters for the SNRs are summarized in Table 2.

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Table 1: Source List at 10.55 GHz with $S_p \geq 0.2$ Jy/beam

l	b	S_p	θ_l	θ_b	S	Remarks
Δl	Δb	ΔS_p	$\Delta\theta_l$	$\Delta\theta_b$		
(° ' ")	(° ' ")	(Jy/beam)	(')	(')	(Jy)	
358 23 49	-00 51 09	0.23	2.55	3.64	0.32	
20	15	0.04	0.47	0.68		
358 24 12	+01 47 54	0.20	2.21	2.50	0.12	
20	20	0.06	0,76	0.75		
358 29 52	+00 04 13	0.44	5.63	4.97	1.86	
20	20	0.08	1.15	0.98		
358 36 33	-00 03 13	0.73	3.36	2.78	1.03	
12	15	0.07	0.41	0.35		
358 37 50	+00 04 08	0.58	2.72	2.80	0.67	
12	12	0.05	0.26	0.26		
358 40 59	-00 05 28	0.38	5.19	3.98	1.19	
15	20	0.04	0.75	0.60		
358 38 40	+01 01 54	0.20	3.61	6.64	0.73	
47	17	0.04	0.95	2.05		
358 47 12	+00 03 38	0.45	3.26	2.52	0.56	
12	15	0.06	0.48	0.38		
358 57 47	-00 43 55	0.51	1.97	2.98	0.45	
12	12	0.05	0.23	0.34		
358 57 35	-00 12 05	0.20	2.92	3.53	0.31	
23	20	0.40	0.79	0.89		
358 57 18	-00 00 21	0.34	3.54	3.01	0.55	
15	15	0.04	0.55	0.47		
359 0 41	-00 02 42	0.44	6.59	5.12	2.25	
20	27	0.08	1.31	1.12		
359 9 60	-00 02 10	0.67	3.45	3.59	1.26	
12	12	0.05	0.33	0.34		
359 10 60	+00 01 36	0.25	3.22	2.29	0.28	
17	23	0.05	0.86	0.57		
359 18 15	-00 49 58	1.07	2.61	2.99	1.26	
11	11	0.06	0.16	0.18		

Table 1 (continued)

359 17 8	-00 15 28	1.25	3.12	3.25	1.92	
11	11	0.03	0.09	0.09		
359 21 50	-00 58 50	0.55	2.48	2.58	0.53	
12	12	0.04	0.25	0.25		
359 25 47	-00 05 18	4.06	4.48	3.33	9.17	
11	11	0.15	0.21	0.16		
359 38 53	-00 15 32	1.41	4.92	5.22	5.48	
12	12	0.08	0.41	0.41		
359 39 4	-00 04 35	1.07	7.40	3.63	4.35	
25	20	0.12	1.21	0.61		
359 44 13	-00 24 30	0.57	4.22	2.89	1.05	
12	14	0.05	0.49	0.33		
359 42 50	-00 01 40	1.24	5.43	3.98	4.06	
12	12	0.06	0.37	0.30		
359 56 51	-00 02 51	43.81	3.55	3.60	84.77	Sgr.A
11	11	1.01	0.11	0.11		
0 10 9	+00 02 50	4.31	5.31	5.59	19.37	
27	23	0.69	1.21	1.19		
0 17 4	-00 28 08	1.02	2.86	4.33	1.91	
12	11	0.06	0.21	0.31		
0 18 10	-00 24 22	0.41	3.88	5.44	1.31	
27	17	0.05	0.79	1.03		
0 22 9	-00 47 09	1.07	2.71	3.95	1.73	
14	12	0.08	0.26	0.37		
0 24 27	-00 31 51	0.81	5.69	4.83	3.37	
17	20	0.11	0.95	0.90		
0 26 32	-00 47 09	0.33	4.19	3.51	0.73	
17	20	0.04	0.76	0.68		
0 29 43	-01 01 12	0.24	2.33	3.78	0.32	
23	14	0.04	0.47	0.79		

Table 1 (continued)

0 29 27	-00 39 49	1.20	3.50	3.22	2.05	
14	17	0.14	0.56	0.50		
0 28 43	-00 24 19	0.23	4.45	3.62	0.56	
27	37	0.05	1.48	1.24		
0 30 43	-00 03 00	8.95	5.46	4.33	32.04	
12	12	0.38	0.36	0.29		
0 30 59	+00 10 42	0.86	3.93	3.68	1,88	
12	12	0.04	0.31	0.25		
0 34 21	-00 50 58	1.48	4.28	3.66	3.51	
11	12	0.07	0.29	0.24		
0 33 38	-00 22 38	0.55	3.53	3.34	0.98	
12	14	0.05	0.42	0.38		
0 33 1	+00 03 57	0.84	4.58	3.58	2.09	
14	17	0.07	0.54	0.44		
0 34 35	-00 37 24	1.51	4.35	3.43	3.41	
11	11	0.06	0.25	0.20		
0 36 8	-00 34 25	0.60	5.65	4.91	2.52	
20	20	0.12	1.21	0.95		
0 36 10	+00 20 10	0.24	3.18	3.98	0.46	
23	17	0.04	0.77	0.95		
0 38 9	+00 37 42	0.49	4.09	3.78	1.15	
12	12	0.03	0.42	0.38		
0 40 2	-00 01 51	23.00	3.65	2.90	36.86	Sgr.B
11	11	1.06	0.20	0.16		
0 49 44	+00 12 12	0.75	2.98	3.16	1.07	
11	11	0.04	0.19	0.20		
0 51 46	+00 05 15	3.07	3.29	3,23	4.94	
11	11	0.08	0.11	0.10		
1 7 49	-00 05 08	3.08	3.09	3.15	4.54	
12	12	0.23	0.27	0.27		

Table 1 (continued)

1 19 28	+00 06 21	0.74	3.61	3.73	1.51
12	12	0.04	0.27	0.26	
1 24 51	+00 14 49	0.21	6.12	5.87	1.14
40	30	0.09	2.44	1.98	
1 42 44	-00 06 50	0.32	6.35	6.93	2.13
40	27	0.11	2.07	2.23	
1 53 25	+00 20 53	0.21	1.60	2.76	0.2
23	17	0.08	0.83	0.86	

Table 2: Parameters for the two new SNRs in the galactic center region

Quantities	G359.1-0.5	G359.0-0.9
Center position, l (°)	359°.1	359°.0
b (°)	-0°.5	-0°.9
RA (1950) (h m)	$17^h42^m.3$	$17^h43^m.7$
Dec (1950) (° ')	-29°56'	-30°15'
Angular diameter, θ_d (')	21'	23'
Integrated flux density at 10 GHz, S_{10} (Jy)	5.1 ± 1	11 ± 2
Mean surface brightness at 10 GHz, Σ_{10GHz} ($W\ m^{-2} Hz^{-1} str^{-1}$)	1.7×10^{-21}	3.1×10^{-21}
Estiamted surface brightness at 5 GHz, Σ_{5GHz} ($W\ m^{-2} Hz^{-1} str^{-1}$)	2.8×10^{-21}	6.9×10^{-21}
Spectral index, α	-0.6	-1.0
Diameter*, D (pc)	38	32
Distance, d (kpc)	6.2	4.8
Galactocentric distance, d_G (kpc)	3.8	5.2
Height from galactic plane, z (pc)	-54	-75
Age+, t (years)	2.4×10^4	1.6×10^4
Expansion velocity, v ($km\ s^{-1}$)	300	400

* Σ-D relation at 5 GHz by Clark and Caswell (1980) was used.

+ Explosion energy of 10^{51} ergs and ambient gas density of n_o=1 H atom cm^{-3} were assumed.

Table 3. Properties of the Galactic Center lobe+

Geometrical center	l = 359°.7
	b = 0°.6
	RA(1950) = 17h 39.4m
	Dec(1950) = -28° 51'
Angular diameter in the longitude direction	θ_l = 1.06°
Linear diameter at 10 kpc distance	D = 185 pc
Height of the lobe top from the galactic plane	θ_b = 1.2°
Linear height of the lobe top	H = 210 pc
Total flux density at 10.5 GHz integrated at $b \geq 0.2°$	S_{10GHz}=132 ± 10 Jy
Spectral index between 5 and 10 GHz	α =-0.1
Electron density at the ridge* (electron temperature of 5000 K assumed)	n_e = 9 cm^{-3}
Mean electron density*	$\bar{n}_e$ = 5 cm^{-3}
Total mass of ionized hydrogen gas*	M = 4 x 10^5 M⊙

* Derived by assuming a thermal gas origin.

+ See Sofue and Handa (1984) for details.

Figure Captions

Fig.1: 10.55 GHz radio continuum map of the 4°x 4° region centered on the galactic center. The map has been smoothed by a 3.6' HPBW gaussian beam. Note a large lobe structure of diameter ∿ 1° centered on l=359°.7, b=0.6° which we call as the Galactic Center Lobe (see the text for discussion). The numbers on the contours represent surface brightness at 10.55 GHz in unit of 8.65 mJy/2.6' beam area, equivalently in 1.36×10^{-22} W $m^{-2} Hz^{-1} str^{-1}$ or 4.0 mK T_b.

Fig.2 a-q : 10.55 GHz radio continuum maps with original resolution of 2.57' HPBW. The mapped region is devided into 16 sections. The unit of the numbers on the contours is the same as in figure 1.

Fig.3: Close up of a region containing two new supernova remnants of shell type, G359.1-0.5 and G359.0-0.9 with diameters of 21' and 23', respectively. The map has been smoothed with a 3.0' HPBW gaussian beam, and large-scale background structures have been removed by applying the background filtering method. The unit of the numbers on contours is 2.7 mK T_b (=9.1×10^{-23} W $m^{-2} Hz^{-1} str^{-1}$= 5.77 mJy/beam area of 2.6' HPBW).

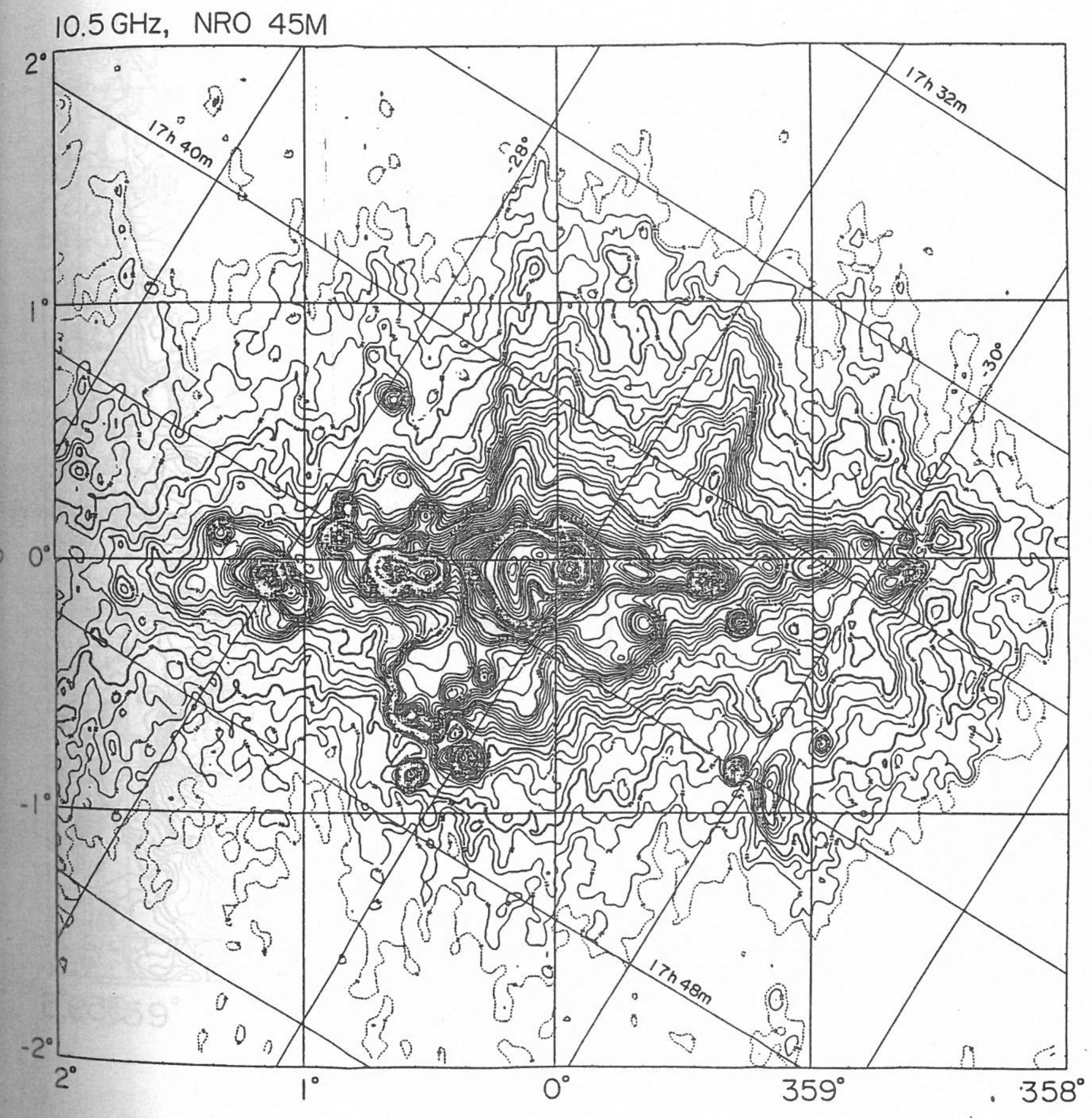

Figure 1.