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HIGH-LATITUDE MOLECULAR CLOUDS: COMPLETENESS OF THE LOCAL SAMPLE AND IMPLICATIONS FOR MOLECULAR SURVEYS

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ABSTRACT

The results of an unbiased survey of CO emission at high Galactic latitudes ($|b| \geq 25°$) are presented. In this paper, the value for ϵ, the fractional completeness of the Blitz, Magnani, and Mundy high-latitude cloud survey, is obtained and found to be 0.55 ± 0.15. Using this value, the following properties of the molecular component of the local interstellar medium are determined: the number of individual clouds within 100 pc of the Sun is ~ 120; the surface filling fraction is $\sim 4.5 \times 10^{-3}$; the total mass is of order $5 \times 10^3\ M_\odot$; and the mass surface density is $0.2\ M_\odot\ \mathrm{pc}^{-2}$.

The north-south asymmetry reported by Magnani, Blitz, and Mundy is confirmed by the unbiased survey. If the distribution of high-latitude clouds mimics the overall CO emissivity for the inner Galaxy, then they would contribute almost $10^8\ M_\odot$, about 10% of the total molecular mass of the Galaxy.

Subject heading: interstellar: molecules

I. INTRODUCTION

The presence of significant quantities of molecular gas at high Galactic latitude ($|b| \geq 25°$) was established by Blitz, Magnani, and Mundy (1984, hereafter Paper I). A catalog of the detections along with maps for a majority of the clouds is presented in Magnani, Blitz, and Mundy (1985, hereafter Paper II). In Paper I, the number of individual clouds and the surface filling fraction in the solar neighborhood (within 100 pc of the Sun) were estimated to be $64/\epsilon$ and $2.5 \times 10^{-3}/\epsilon$, where ϵ is the fractional completeness of the catalog.

Since the catalog is optically selected from regions of low extinction, it may be biased, and the value of ϵ could, in principle, be quite small. In this paper, the results of an unbiased survey used to determine ϵ are presented. The number, total mass, and surface mass density of the high-latitude molecular clouds corrected for incompleteness are calculated. These values are used to estimate the contribution of clouds similar to those found at high Galactic latitude with respect to the emission detected in molecular surveys.

II. OBSERVATIONS

The survey was carried out in the $J = 1$–0 transition of CO at the 5 m telescope of the Millimeter Wave Observatory[2] (MWO) near Fort Davis, Texas, in 1984 June and November. A description of the observing procedure and calibration is included in Papers I and II. At 115 GHz, the 5 m dish has a $2\farcm3$ beam (HPBW). During the run, typical single-sideband system temperatures referred outside the atmosphere ranged from 700 to 1300 K. The spectrometer was centered at a velocity of 0.0 km s^{-1} relative to the local standard of rest (LSR). Velocity coverage in the 250 kHz filters was ± 89.5 km s^{-1}. Since the average velocities of all the cataloged clouds are within ± 26 km s^{-1} of the LSR (see Paper I), the velocity coverage ensures that any potential object will be detected.

Standard chopper wheel calibrations were performed before observing every new source, and standard sources such as NGC 2264 and M17 were observed periodically. The variation in antenna temperature in NGC 2264 was 15% during the run.

We observed 2500 points by stepping the telescope through $10 \times 10(\cos b)$ deg^2 grids: 1750 points in the northern Galactic hemisphere and 750 in the southern Galactic hemisphere. Each grid consisted of 100 sampled lines of sight separated by 1° intervals of l and b (384 points were sampled in 1° intervals of α and δ). The integration time was chosen to produce ~ 0.3 K rms noise temperature in the 250 kHz resolution spectra.

The locations of the grids in Galactic coordinates are shown in Figure 1. The positions of the grids were chosen so that as much of the sky was covered as possible. Because the telescope was not available to us during LST 15^{h}–24^{h}, the southern Galactic hemisphere between $l = 120°$ and $l = 240°$ was not sampled. Table 1 lists the position of the grids, the number of points sampled, the typical rms noise temperature, and the number of detections in the grids, if any.

III. RESULTS

Carbon monoxide emission was detected along nine lines of sight: four in the northern hemisphere and five in the southern hemisphere. Table 2 lists the positions of the detected lines, the antenna temperature, the velocity centroid with respect to the LSR, and the cloud number from Paper II if the detection was previously cataloged. Three of the detections occur in sources not previously cataloged, all in the southern hemisphere.

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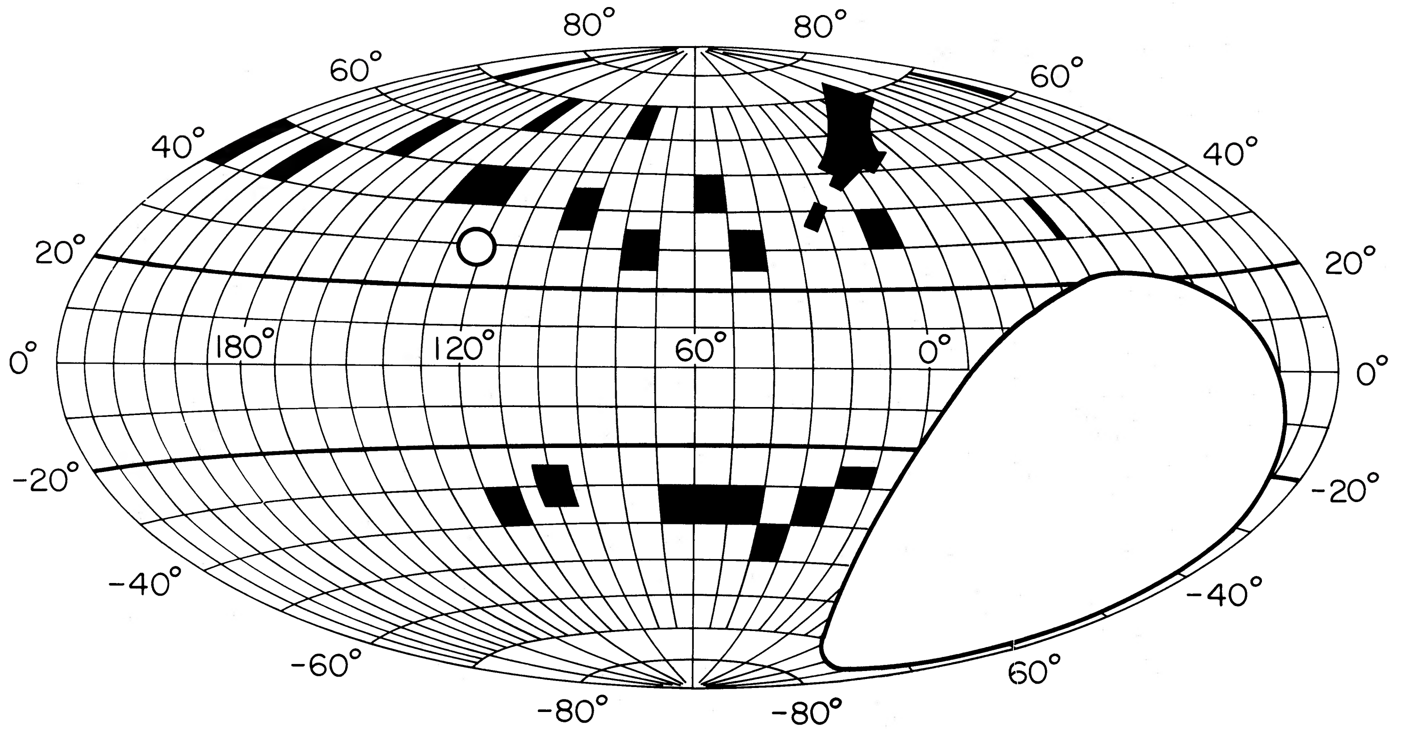

FIG. 1.—Galactic coordinate all-sky map of the areas surveyed in 1° intervals of *l* and *b*. The irregularly shaped area at $l \approx 350°$ was observed in 1° intervals of α and δ. The blank areas could not be observed with the Texas instrument.

Three of the our detections in the northern Galactic hemisphere occur near $l = 5°$, $b = 35°$, where there are many separate but obviously related areas of molecular emission. In Paper II we designate this region complex 24, consisting of clouds 33–39. A cloud is defined as an individual entity with a closed contour of CO(1–0) antenna temperature at 0.5 K. Some of the objects in this complex are Lynds (1962) or Sharpless (1959) objects, including the well-studied local dust cloud L134.

TABLE 1

GRID POSITIONS

GRID CENTRAL POSITION				
l (1950)	*b* (1950)	NUMBER OF SAMPLED POINTS	rms (K)	DETECTIONS
5°	+35°	100	0.30	3
15	−27.5	50	0.35	1
25	−35	100	0.30	0
35	−45	100	0.30	0
45	+30	100	0.30	0
45	−35	100	0.30	0
55	+45	100	0.30	0
55	−35	100	0.30	0
65	−35	100	0.30	1
75	+30	100	0.30	0
85	+65	100	0.30	0
95	+40	100	0.30	1
100	−30	100	0.20	2
115	−35	100	0.30	1
125	+45	100	0.30	0
135	+65	100	0.30	0
135	+45	100	0.30	0
175	+55	100	0.25	0
205	+75	100	0.30	0
205	+45	100	0.30	0
235	+45	100	0.30	0
252	+65	41	0.30	0
311	+35	25	0.40	0
23	+38	28	0.30	0
350	+60	356	0.20	0

IV. DISCUSSION

With the above data, one can determine a value for the fractional completeness ϵ. The higher detection rate in the southern Galactic hemisphere seems to reflect the asymmetry between the north and south Galactic hemispheres noted in Paper II: 70% of the molecular complexes are located in the southern Galactic hemisphere. If the total area of the mapped complexes is used instead of the total number of objects, the distribution percentage does not change. However, if one calculates an average area for the mapped complexes and attributes this value to the unmapped sources, the percentage of the area covered by objects in the south rises to 80%. On this basis, for the succeeding calculations the distribution of objects

TABLE 2

DETECTIONS

R.A. (1950)	Decl. (1950)	*l* (1950)	*b* (1950)	T_A^* (K)	$v_{\rm LSR}$ (km s^{-1})	Cloud Number (Paper II)
$00^h12^m45^s.7$	+21°49′35″	112°	−40°	1.0	−5.6	...
15 48 43.5	−3 12 20	5	+37	5.1	+2.1	37
15 49 51.0	−4 27 27	4	+36	2.0	+2.9	36
15 50 41.5	−2 34 33	6	+37	1.2	+2.7	37
16 43 14.1	+60 15 26	90	+39	1.3	−23.2	41
19 59 27.2	−31 29 22	10	−28	3.6	+6.5	45
21 39 48.9	+5 3 37	61	−34	2.6	−6.2	...
23 20 32.8	+31 58 37	102	−27	1.6	−4.7	...
23 22 44.6	+33 14 12	103	−26	2.1	−5.2	56

is set at 75% ± 9% in the southern hemisphere and 25% ± 5% in the northern hemisphere.

Using Poisson statistics, the number of detections for a given number of observed lines of sight and their corresponding 1 σ variation can be calculated. The 1 σ upper limit for the number of lines of sight needed to detect nine sources out of 2500 sampled points with the above distribution is one detection for ~290 lines of sight. The 1 σ lower limit is one detection for ~160 lines of sight, and the best fit is one detection in ~220 sampled lines of sight. With a predicted detection rate from Paper I of one detection in $\sim 400\epsilon$ lines of sight, the above results yield a range for the fractional completeness of $0.40 < \epsilon < 0.72$, with a best value of $\epsilon = 0.55$.

Using these results, some of the cloud properties determined in Paper I can be more accurately estimated. The total number of individual clouds is 120^{+40}_{-30} (the number of complexes is about half this figure), and the surface filling fraction becomes 4.5×10^{-3}. In the solar neighborhood, the high-latitude molecular clouds would contribute $\sim 5 \times 10^3\ M_\odot$ of material distributed within 100 pc of the Sun, which results in a mass surface density of $\sim 0.2\ M_\odot\ \text{pc}^{-2}$.

This value is of about 40% of the surface density of giant molecular clouds (GMCs) in the solar neighborhood calculated in Paper I but is only about 10% of the total surface density of molecular gas at 10 kpc (Bloemen *et al.* 1985).

V. IMPLICATIONS FOR MOLECULAR SURVEYS

If the local high-latitude molecular clouds are pervasive throughout the Galaxy, they would constitute the low-mass component of the molecular cloud spectrum. Using the quantities calculated above, the contribution of the small clouds in molecular surveys can be determined.

The mean free path for a line of sight λ for the high-latitude clouds near the Sun is 15 kpc. For GMCs, assuming that their local number density is equal to the local number density of OB associations (Blitz 1980), λ is about 18 kpc. Thus, in the solar vicinity a random line of sight is about equally likely to intersect a GMC as a high-latitude–type cloud. If the distribution of small clouds in the Milky Way mimics the CO emissivity (Scoville and Solomon 1975; Gordon and Burton 1976), λ will decrease to ~3–5 kpc at the peak of the molecular ring. A weighted mean λ for a path at $l = 30°$, $b = 0°$ is ~10 kpc. The mean value of $\int T_A{}^* dv$ for the high-latitude molecular clouds is 3.5 K km s^{-1} (Paper II). Thus at $l = 30°$, one expects a total contribution to the CO emissivity from clouds of this type to be ~7 K km s^{-1}. Solomon, Scoville, and Sanders (1979) quote a value $\int T_A{}^* dv = 204$ K km s^{-1} along this line of sight. Although this value is likely to be high by about 30% because of the large error pattern of the old 36 foot (11 m) telescope, we expect the contribution from the small clouds to be no more than ~5%–10% of the total CO emissivity if the relative number of small clouds and GMCs is constant.

The total mass contribution of the small molecular clouds to the overall molecular mass of the Galaxy may be estimated for the two distributions mentioned above. If the distribution of the high-latitude–type clouds is uniform throughout the Galaxy, the total number of clouds within 10 kpc of the Galactic center is $\sim 1 \times 10^6$, and the total mass (based on the average mass per cloud derived in Paper II) is $\sim 4 \times 10^7\ M_\odot$. If the distribution mimics the increase in GMC distribution between 4 and 8 kpc (Scoville and Solomon 1975; Gordon and Burton 1976), the total mass in the small clouds rises to $\sim 8 \times 10^7\ M_\odot$. This value is ~10% of the value of $1.1 \times 10^9\ M_\odot$ obtained by Bloemen *et al.* (1985) from gamma-ray data; a small but substantial fraction of molecular material resides in these clouds.

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