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SOUTHERN GALACTIC PLANE CO SURVEY

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Preliminary results are presented for a survey of J = 1-0 ^{12}CO emission being carried out at 3' arc intervals along the southern galactic plane in the range $294° \leqslant \ell \leqslant 358°$, $-0°.075 \leqslant b \leqslant 0°.075$. The longitude-velocity distribution shows well-defined terminal velocities, and is similar to the distribution at corresponding longitudes north of the galactic centre. However, the radial distribution of CO suggests that the southern CO, while concentrated inside the solar circle as in the north, is on the average located about 500 pc further from the galactic centre. Limited estimates of cloud sizes and masses suggest ranges greater than those deduced in previous surveys.

Key words: carbon monoxide; southern galactic plane.

Introduction

Of all the molecules observed in the Galaxy, carbon monoxide is the most abundant species. Observations of the J = 1-0 transition of CO at 115 GHz are most valuable in delineating clouds of cold, dense gas in the Galaxy. These clouds are thought to be predominantly molecular hydrogen, which is not observable at radio frequencies.

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Previous studies of the distribution of CO in the galactic plane (1-5) revealed that the molecular clouds are concentrated in the galactic centre and in a ring extending from 4 to 8 kpc from the centre. This is in marked contrast to the more extensive distribution of atomic hydrogen (HI) observed using the 1.4 GHz line.

The early surveys of galactic CO used telescopes in the northern hemisphere and concentrated on longitudes $0° \leqslant \ell \leqslant 80°$. The galactic plane was grossly undersampled, which hindered the detection of continuous CO features analogous to the structures which have been interpreted as spiral arms in the HI surveys. More recently (6) a well-sampled survey of the region $12° \leqslant \ell \leqslant 60°$ and $-1° \leqslant b \leqslant 1°$ has been made which gives clear evidence that large-scale structures are present in the CO emission. Since the molecular clouds are the sites where stars are currently forming, their distribution is likely to be similar to that of OB stars and HII regions, objects which delineate the spiral arms seen in external galaxies.

Until recently CO observations of the southern portion of the galactic plane have not been available. We report here the preliminary results from a survey of J = 1-0 CO emission, which will cover a longitude range $294° \leqslant \ell \leqslant 358°$ and a latitude range $-0°.075 \leqslant b \leqslant 0°.075$. Up to the present an area of 6.5 deg^2 (two-thirds of the total area) has been observed at 3' arc intervals. Some earlier results have been reported by McCutcheon et al. (7).

The goals of the southern CO survey are to compare the molecular distribution in the south with that in the north in order to detect large-scale galactic structure similar to that suggested by observations of the HI, other molecules, and radio and optical observations of ionized (HII) regions, and to determine the sizes and masses of molecular clouds and their relationship to star formation.

OBSERVATIONS

The observations were made during the periods September-December 1980 and June-July 1981 with the 4-m Cassegrain telescope at the CSIRO Division of Radiophysics (8), which has a beamwidth of 2'.8 arc at 115 GHz and a pointing accuracy of 30" to 40" arc. The zenith atmospheric opacity was measured daily and lay in the range 0.2 to 0.3 neper.

The receiver used a cryogenically-cooled Schottky-barrier mixer, similar to that described by McCulloch et al. (9). The single-sideband system temperature was 1000 K (assuming equal sideband gains). A nominal temperature scale has been assumed for the results in this paper.

The CO spectra were measured using a 512-channel acousto-optical spectrograph (AOS) with a radial velocity coverage of 244 km s^{-1} and an effective resolution of 0.6 km s^{-1} (10, 11). Optimum operation of the AOS was achieved by switching between the on-axis telescope beam and a reference beam at a 0.5 Hz rate. Because CO emission is extended along the galactic plane we had to ensure that the reference beam was free of emission. This was achieved by the arrangement shown in Fig. 1. A reciprocating plane mirror was pneumatically driven in front of the 115 GHz feed horn at the Cassegrain focus of the telescope. The mirror diverted the horn illumination away from the sub-reflector to a 54-mm diameter Teflon lens which collimated the beam and directed it to a second plane mirror on the edge of the main paraboloid. The second mirror could be steered to direct the reference beam at any angle relative to the main beam. The reference beamwidth, determined by the Teflon lens, was $3^{\circ}\!.6$. When this beam was directed at a test position on the galactic plane no CO emission could be detected. During the survey of the galactic plane the reference beam was offset from the main beam in azimuth by $6^{\circ}\!.6$ cosec (zenith angle), and in elevation by $6^{\circ}\!.8$, ensuring that the reference beam was usually several degrees off the plane.

The elevation offset of the reference beam was chosen to keep the antenna temperatures for the main and reference beams approximately equal over the elevation range 40° to 80°. Equalizing the antenna temperatures improved the instrumental baseline considerably. To ensure precise equality of the signal and reference levels at the AOS, the intermediate-frequency amplifier gain was controlled by an AGC loop with a response time shorter than the travel time of the pneumatic beam switch (100 ms).

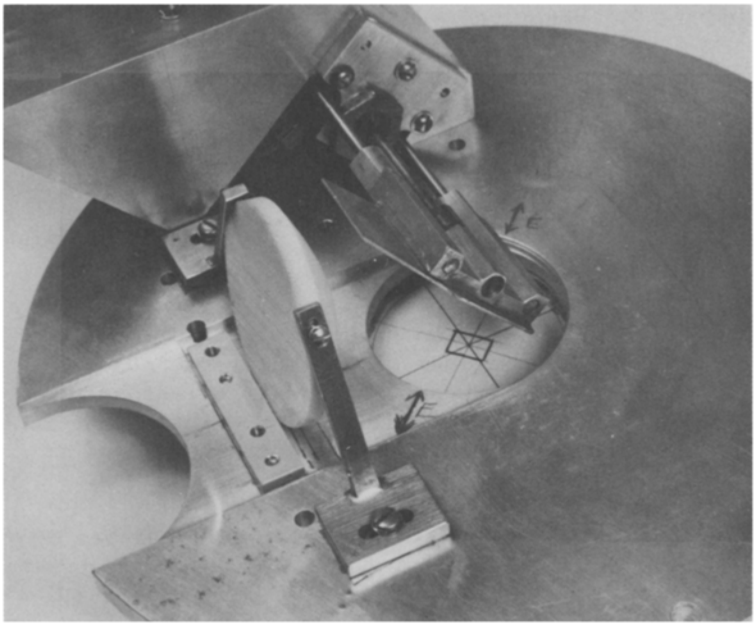

Figure 1. Beam-switching arrangement used at 115 GHz. The plane mirror on the right is pneumatically driven to switch the feed horn illumination on to the Teflon lens at left. (The position of the horn is marked by a rectangle.) A collimated beam from the lens is steered by a second plane mirror (not shown) to any angle relative to the main beam.

For a given observation a grid of nine positions spaced 3' arc was observed under computer control, covering $\Delta\ell$ = 0', ±3' and b = 0', ±3'; adjacent observations were spaced by 9' arc. During any one day observations were made at 6° intervals in longitude over the full longitude range. To remove the instrumental baselines from the spectra, the observations were interspersed with observations at reference positions 10° above or below the galactic plane.

For present purposes the nine spectra in a grid were summed to form a single spectrum which was then smoothed to an effective velocity resolution of 1.6 km s^{-1}. These parameters are comparable to those of the survey by

Cohen et al. (6). The resulting spectra have an rms noise of about 0.2 K; examples are shown in Figs 2 and 3.

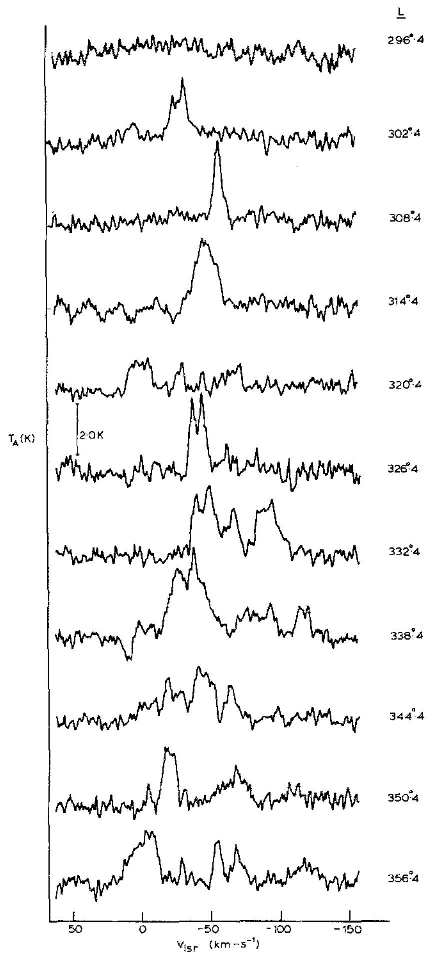

Figure 2. A set of CO profiles every 6° in longitude showing the complete range of longitude covered in one day's observations. The effective beamwidth is 9' arc and the effective resolution in radial velocity is 1.6 km s^{-1}.

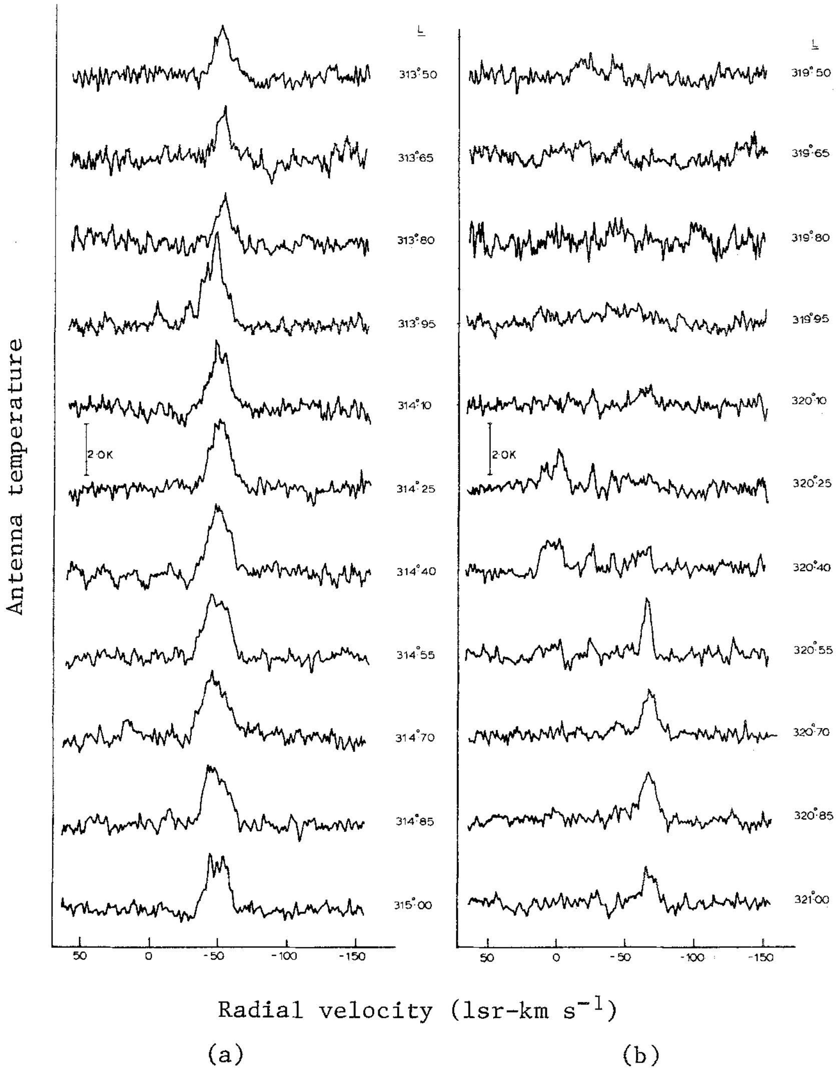

Figure 3. Two sets of CO profiles measured every 0°.15 in longitude over a total range of 1°.5. There is little variability seen in Fig. 3(a), but considerable variability in Fig. 3(b).

Large-Scale Structure in CO Emission

As seen from the profiles in Figs 2 and 3, most of the CO emission occurs at negative radial velocities, indicating that the CO clouds with b near 0° are located predominantly within 10 kpc of the galactic centre. This is also characteristic of the northern CO distribution.

For the southern observations the distribution of ^{12}CO as a function of galactocentric radius has been derived by McCutcheon et al. (7). Further analysis (based on 30% of the observations) yielded the emissivity as a function of radius shown in Fig. 4. The emissivity is defined by

$$\varepsilon(R_j) = \frac{1}{2} \sum_{\ell} \left[\sum_{R_j} \frac{T_A(V_i)\Delta V_i}{\Delta r_j} \right] \quad \text{K km s}^{-1} \text{ kpc}^{-1}.$$

The quantity within brackets is the sum of the intensities ($T_A(V)$) over a given velocity interval (ΔV) at a given longitude and weighted by the width of the annulus Δr. The weighting accounts for the variations in the radial velocity gradient. The quantity in brackets is then summed over all longitudes; the factor 1/2 is applied only to $\varepsilon(R_j)$ for $R_j \leqslant 10$ kpc where each annulus is sampled twice. We have assumed that near and far path length increments contribute equally on average to $\varepsilon(R_j)$.

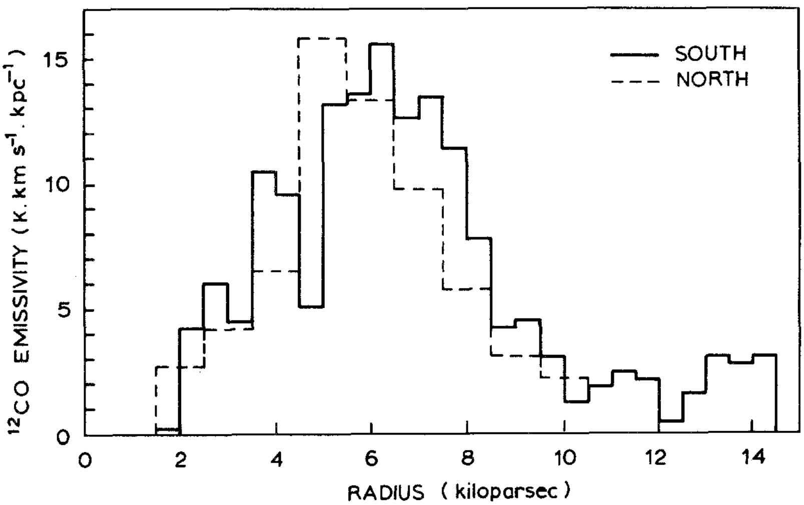

Figure 4. Distribution of CO emissivity with galactocentric radius. The dashed line is the northern CO distribution (Sanders and Scoville, private communication).

The general characteristic of the distribution is similar to that found in the north in that the CO is concentrated within a small range of radii. For the histogram in Fig. 4 we obtain a mean radius $\bar{R}$ = 6 to 6.5 kpc, and half amplitude values at radii 3.5 and 8.5 kpc. Corresponding values from Burton and Gordon's (4) northern CO survey are: $\bar{R}$ = 5.7 kpc, and half-maxima at 4 and 8 kpc. The main peak in the emissivity in Fig. 4 is centred at 6.5 kpc.

Thus the peak in the southern CO distribution appears to be shifted outward by about 1 kpc compared to that in the north. The distribution of OH maser sources (J.L. Caswell, personal communication) in a longitude range similar to that of this survey is similar to the CO distribution, with a mean radius $\bar{R} \simeq 6.7$ kpc and a similar width. This asymmetry in the CO distribution can also be seen in the spiral arm pattern delineated by HII regions (12) in the range $285° \lesssim \ell \lesssim 340°$.

Large-scale structures in the CO emission are best seen in the variation of intensity as a function of radial velocity and galactic longitude. Figure 5 shows a longitude-velocity distribution based on a reduction of two-thirds of the southern observations. There is a striking similarity between this distribution and the northern longitude-velocity distribution published by Cohen et al. (6), which contains data sampled at approximately the same intervals in longitude and, as already mentioned, has similar beam size and resolution in velocity. The terminal velocities (i.e. the maximum negative velocity at a particular longitude) at longitudes $305° < \ell < 335°$ (which includes the Sagittarius and Norma-Scutum spiral arms suggested by HI emission) correspond very closely in magnitude to those occurring for $55° > \ell > 30°$. Minima or areas of low CO emission between the spiral arms are seen in both distributions. The peak velocity is about 120 km s^{-1} in both surveys.

A striking difference between the northern and southern surveys is the absence in Fig. 5 of extensive emission near V = -10 km s^{-1} for $300° < \ell < 340°$. Corresponding emission (at +10 km s^{-1}) in the northern survey is attributed to a "local" spiral arm near the Sun. Its patchy appearance in Fig. 5 may be a consequence of the more restricted latitude sampling of the southern survey, which could lead to poorer sampling of gas clouds close to the Sun. Further sampling in latitude is planned for this survey.

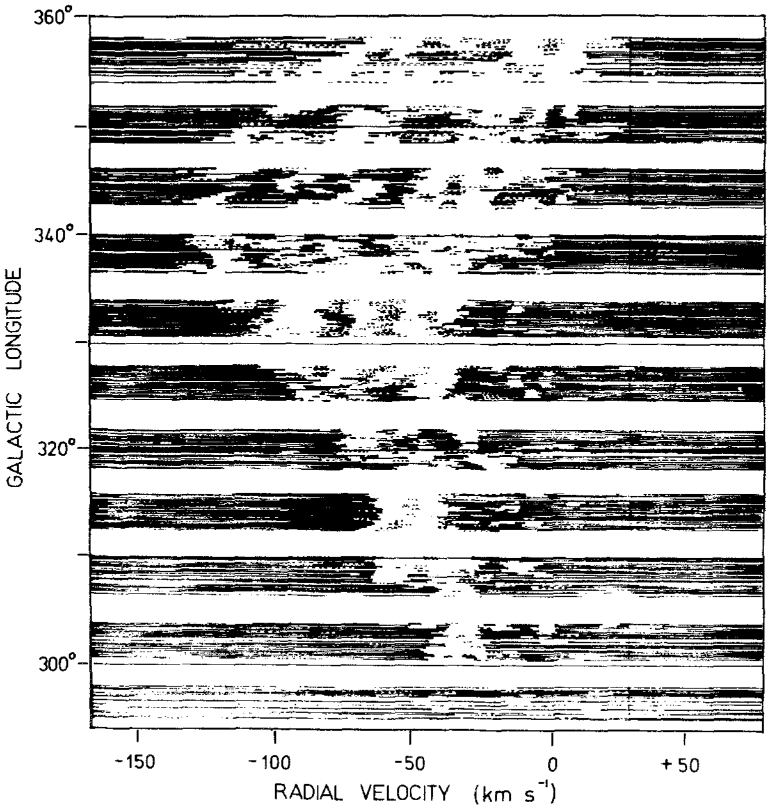

Figure 5. The variation of CO emission is shown in a galactic longitude-radial velocity plot. White represents significant CO emission. Dashed lines show minima or ranges of low emission.

Estimates of Molecular Cloud Parameters

Cloud sizes and masses have been estimated previously in several surveys. Burton and Gordon (4) sampled the plane with a 1' arc beam at intervals of 12' arc and estimated both from observations and model studies that the molecular clouds had diameters between 5 and 17 pc and an average mass of 2×10^3 $M_\odot$. Solomon et al. (5) reported on more extensive observations, although still largely undersampled. They claimed to be detecting giant molecular clouds with diameters ranging from 20 to 80 pc and an average mass of 5×10^5 $M_\odot$. Szabo et al. (13) detected two well-defined clouds having diameters in the range 27 to 42 pc and masses in the range (2-4) × 10^5 $M_\odot$, values which support those of Solomon et al.

For our results Fig. 3(b) shows the variability that can occur between spectra separated by 9' arc in longitude. When the nine individual spectra that form each average were examined, variability could also be seen on a 3' arc scale. On an even larger scale, variability is also detected over angular separations 40' to 50' arc. If we treat these variations as indications of discrete clouds, then with some assumptions we can make rough estimates of sizes and masses. Table I lists five clouds in order of increasing angular size. Clouds 1 and 2 show the 3' arc variations, clouds 3 and 4 the 9' arc variations, and cloud 5 has a scale size of 50' arc. Distances, and hence diameters, were calculated using analytic approximations (14) to the Schmidt galactic rotation curve (15). In the table, the two kinematic distances and corresponding diameters are shown. However, the underlined values are preferable, being more consistent with the distances of H_2CO clouds seen in similar directions and with similar velocities (16). For HII regions in the direction of cloud 5, OH absorption lines indicate the "near" distance, while HI and H_2CO absorption suggest the "far" distance. We have assumed T^*_{13}/T^*_{12} = 1/5.5 (5), and used an LTE calculation to obtain ^{13}CO column densities, which were then converted to molecular hydrogen column densities (17).

The results in Table I suggest that cloud masses can cover a range wide enough to include the divergent estimates of the previous surveys. Clouds 1 to 4 lie in the lower contour regions of continuum peaks of 5 GHz continuum maps (18) while cloud 5 is situated between strong peaks of a large continuum complex. Furthermore, H109α and H110α recombination lines have been detected (J.L. Caswell and R.F. Haynes, personal communication) near the positions of clouds 1, 4 and 5 and with velocities similar to the CO values. Thus it seems reasonable that these clouds are all associated with HII regions, with the largest cloud near a giant thermal complex.

The sizes and masses in Table I are rough estimates only. A region fully sampled in two dimensions is required for more complete information on cloud sizes; more reliable masses can be estimated when ^{13}CO observations become available.

Table I. Physical parameters of clouds

Cloud	Central longitude °	Central velocity ($km\ s^{-1}$)	FWHM velocity width ($km\ s^{-1}$)	Distance (kpc)	Diameter (pc)	Mass $\times 10^5\ M_\odot$
1	311.25	-53.8	9.5	4.5,8.7	3.9,7.6	0.017,0.064
2	347.25	-68.1	9.5	6.6,12.9	5.8,11.3	0.036,0.14
3	312.60	-10.0	12.5	0.7,12.8	1.8,33.5	0.001,0.44
4	319.65	-22.0	7.0	1.5,13.7	3.9,35.9	0.005,0.40
5	337.05	-68.0	19.1	5.2,13.2	75.6,191.9	8.5,54.8

Summary

Observations of the J = 1-0 ^{12}CO emission are being made at adjacent beam positions in the range $294° \leqslant \ell \leqslant 358°$, $-0°.075 \leqslant b \leqslant 0°.075$. The area of sky already observed is 6.5 deg^2.

The profiles in Fig. 2 and the longitude-velocity plot in Fig. 5 show the clumpy nature of the CO-emitting regions and the predominance of negative velocities; the distribution in Fig. 5 also shows well-defined terminal velocities. Similar characteristics are observed in the northern CO distribution (6).

The radial distribution in Fig. 4 shows that the CO is located predominantly inside the solar circle, similar to the CO distribution in the north, but is somewhat broader and shifted further outward in radius by about 0.5 to 1 kpc.

Variability in CO features is detected on several angular scales, and sizes and masses estimated for five clouds cover a wide range. It is probable that a continuum of sizes exists, and not just a small range as argued previously (4,5). More complete information on sizes and masses can be obtained only from two-dimensional mapping and ^{13}CO observations.

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