A SURVEY OF RADIO RECOMBINATION LINES USING THE OOTY RADIO TELESCOPE AT 328 MHZ IN THE INNER GALAXY

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ABSTRACT

A survey of radio recombination lines in the Galactic plane with longitude $-32^\circ < l < +80^\circ$ and latitude $b < \pm 3^\circ$ using Ooty Radio Telescope (ORT) at 328 MHz is reported. ORT observations were made using a New Digital Backend (NDB) recently added to the telescope. With the NDB ORT had a beam of $2\times 2$ sec($\delta$) and a passband of $\sim$1 MHz in the spectral line mode. The above-mentioned Galactic region was divided into $2^\circ \times 2^\circ$ patches with the ORT beam pointed to the center. The ORT observations form a study of the distribution of extended low-density warm-ionized medium (ELDWIM) in the inner Galaxy using H271$\alpha$ RLs. By obtaining kinematical distances using $V_{lsr}$ of the H271$\alpha$ RLs, the distribution of ELDWIM clouds within the inner Galaxy has been deduced for the region given above.

Key words: H I regions – ISM: abundances – radio lines: ISM

Online-only material: color figures

1. INTRODUCTION

Unsuccessful preliminary attempts to detect radio recombination lines (RRLs) from hydrogen were made by Egorova & Ryzkov (1960) with the Pulkovo telescope. A successful detection of RRLs was made in 1964 April using an improved radio meter with the 22 m radio telescope at Lebedev Physical institute in Puschino. Sorochenko and Borodzich detected the hydrogen RRL H90$\alpha$ ($\lambda = 3.38$ cm) toward the omega nebula. Independently, at about the same time another group (Dravskikh et al. 1965) also detected a convincing RRL H104$\alpha$. Following this many researchers (Lilley et al. 1966; Goldberg & Dupree 1967; Gottesman & Gordon 1970) detected RLs. Subsequent attempts (Batty 1976) to detect RRLs at lower frequencies ($<500$ MHz) seem (Anantharamaiah 1985a, 1985b) to have failed due to non-availability/development of radio telescope hardware. It was already known (Shaver 1975) in the community that stimulated emission ($kT/h \nu = \text{spontaneous}$) would boost RRLs at lower frequencies. Apparently, RRLs at frequencies below 500 MHz had a larger bandwidth (BW) or more RRL transitions (Roshi & Anantharamaiah 2000) compared to only one observable transition (H271$\alpha$) with the recent NDB.

ORT observations have been made with the recently added NDB (Prabu 2010). In the spectral line mode, with NDB, ORT provided a passband of 1.2 MHz and a beam size of $2^\circ \times 2$ sec($\delta$). The Galactic region between $-32^\circ < l < +80^\circ$ and $b < \pm 3^\circ$ was divided into patches of $2^\circ \times 2^\circ$ with ORT pointed toward the center of each patch. ORT observed these 165 positions distributed in 3 rows and 55 columns for $\sim 3$ hr per pointing. Some of the positions were skipped due to the existence of earlier observations, a shortage of telescope time, and severe interference at higher declinations. For technical reasons H271$\alpha$ seemed to be the only appropriate RL for ORT with NDB. Kinematical distances toward H271$\alpha$ line emitting regions were obtained using a differential Galactic rotation curve (Sofue et al. 2009) which gave a distribution of extended low-density warm-ionized medium (ELDWIM) clouds in the inner Galaxy. The current ORT observations aimed to obtain the distribution of ELDWIM in the inner Galaxy and to obtain new RL detections from above and below the Galactic plane at 328 MHz.

2. OBSERVATIONS

ORT is situated near the town Ooty, south India at a longitude of $283.3$ and latitude of $11.4$. ORT (Swarup et al. 1971) is an off-axis parabolic cylinder with a length of $530$ m and width of $30$ m. The telescope is located on a hill which has a natural slope of $11.4$ equal to the geographical latitude of the place. This gives it the feature of an equatorial mount. The operating frequency of the telescope is centered at $326.5$ MHz with a maximum BW of $15$ MHz at the front end. The reflecting surface of the cylinder is made of 1100 stainless steel wires running parallel to each other along the entire length of the telescope. An array of 1056 half-wave dipoles in front of a 90$^\circ$ corner reflector forms the primary feed of the telescope. The 1056 dipoles are in groups of 48. The signals received by these groups are added in phase to form 22 group outputs, each known as a module. The telescope
is divided into a northern part and a southern part. The northern modules are designated as N1 to N11 and the southern modules as S1 to S11. The beamwidth due to each module is $2\deg$ in the east–west and $2\deg/\sec(\delta)$ in the north–south directions, where $\delta$ is the declination. This forms the observing mode and beam for the current project of RL observations.

The RRL observations were made using an NDB (Prabu 2010) which could be operated in narrowband mode or broadband (10 MHz) mode. The narrowband mode was the spectral line mode which provided a BW of 1.2 MHz. This small BW restricted the observation of only 1 RL at a time. The transition selected was H271$\alpha$ which has a rest frequency of 328.958 MHz. ORT has a large front-end BW and the NDB’s 1.2 MHz BW could have accommodated any of the nearby RLS. But due to non-availability of a broadband amplifier for the local oscillator (LO) use of ORT’s dedicated amplifier with a $−3 \text{ dB}$ gain BW of 2 MHz was employed. This restricted the freedom to deviate from ORT’s central LO feed frequency of 296.5 MHz. A symbolic block diagram of the instrument setup is shown in Figure 1. The observations were carried out using dual frequency switching with a shift of $\Delta V_{\text{LSR}} = 300$ or 400 kHz. This magnitude of shift ensured that there was no overlap of the associated carbon RL C271$\alpha$ with H271$\alpha$ between two shifted spectra. The $V_{\text{LSR}}$ difference between C271$\alpha$ and H271$\alpha$ is $\sim 150$ km s$^{-1}$. With this arrangement a spectral BW of approximately 300 km s$^{-1}$ in $V_{\text{LSR}}$ could be covered. At a frequency of 328 MHz differential frequency roughly transforms into differential velocity according to $\Delta V = c \cdot \Delta v/\nu$.

The exact BW of the spectral line mode was decided by the sampling frequency of the NDB, which was nearly 2.45 MHz, giving a BW of half the sampling frequency as decided by the Nyquist sampling rate, 1.225 MHz. The resolution of the observed band then depends upon the number of FFT points performed on the data,

$$\Delta V_{\text{res}} = \frac{\text{BW}}{n_{\text{FFT}}}.$$ (1)

In the present case $n_{\text{FFT}} = 256$ throughout the observations, so $\Delta V_{\text{res}} = 4.785$ kHz or $\Delta V_{\text{res}} = 4.373$ km s$^{-1}$. This resolution is acceptable for the hydrogen RL which is of primary interest in the present observations. However, the same cannot be said for the carbon RL. Being heavy and considering its origin from cold regions, its line width could be completely contained within this resolution. So the carbon RL is considerably smoothed out.

3. DATA ANALYSIS AND CALIBRATION

The frequency switching per second resulted in two sets of power spectra corresponding to different settings of LO, LO1 and LO2. Conventionally, spectra corresponding to LO1 are called $T_{\text{on}}$ and those corresponding to LO2 $T_{\text{off}}$. A simple $T_{\text{on}}/T_{\text{off}} = 1$ eliminated the background continuum power while simultaneously correcting for the gain variation across the band. A folding of $T_{\text{on}}/T_{\text{off}} − 1$ would average the switched spectra further giving a $1/\sqrt{2}$ improvement in rms. Due to the presence of interference the spectra ($T_{\text{on}}/T_{\text{off}} − 1$) had to be intermittently inspected during averaging. This was done using an algorithm (Baddi 2011a) which detected interference and clipped it. The clipped portion was replaced by noise of equivalent standard deviation corresponding to the spectrum plus a baseline connecting the average of a few channel values adjacent to the two sides of the region affected by interference. ORT data were processed in this manner. Further, the folded spectra were corrected for baselines by polynomial fitting avoiding the regions of astronomical lines. Calibration of the spectra was done by performing power measurements on the source and cold sky. $T_{\text{on}}$ or $T_{\text{off}}$ is a measure of continuum power, $T_{\text{on}}/T_{\text{off}} − 1$ gives the line temperature in units of $(T_L/(T_C + T_e))$. To express the line in K it is necessary to know the value of the continuum temperature $T_C$. When the telescope is pointed toward a source the power level in $T_{\text{on}}$ or $T_{\text{off}}$ also includes the electronic-spill-over contribution $T_e$. With this, the temperature ($T_{\text{onsrc}}$) corresponding to $T_{\text{on}}$ or $T_{\text{off}}$ when the telescope is on the source is

$$T_{\text{onsrc}} = T_{C} + T_{e} = 0.65T_{C} + T_{e},$$ (2)

where 0.65 is the beam efficiency of ORT. Similarly, when the telescope is pointed toward the cold sky (sufficiently away from the source toward a cold region in the sky keeping the declination constant) we have

$$T_{\text{offsrc}} = 0.65T_{\text{coldsky}} + T_{e}.\quad (3)$$

Using these measurements (which are power levels in dBm) the continuum temperature $T_C$ can be obtained as

$$T_C = \frac{123}{0.65} \left[ \frac{T_{\text{onsrc}}}{T_{\text{offsrc}}} - 1 \right] + T_{\text{coldsky}},$$ (4)
Figure 3. ORT H271α RL observation.

(A color version of this figure is available in the online journal.)
Figure 3. (Continued)
Figure 3. (Continued)
where $T_{\text{coldsky}} = 36 \text{ K}$ and $T_e = 100 \text{ K}$. This value for $T_e$ also includes the spill-over contribution. A useful expression for $T_C$ in terms of measured power $P$ in dBm is

$$T_C = \frac{123}{0.65} \left(10^{\frac{P-1}{10}} - 1\right) + T_{\text{coldsky}}. \quad (5)$$

Now calibration is given by

$$\frac{T_L}{T_C} = \frac{T_{\text{on}} - T_{\text{off}}}{T_{\text{off}}} \left(\frac{T_C + T_e}{T_C}\right); \quad T_L = \frac{T_L}{T_C} T_C. \quad (6)$$

The final spectrum is multiplied by $T_C + T_e$ to calibrate the line in K. Measured temperatures toward all the positions are shown in Figure 2. $T_C$ measurements in the plane ($b = 0^\circ$) are in very good agreement with previous observations (Roshi & Anantharamaiah 2000).

The final calibrated spectra obtained toward all the positions in the Galactic region $-32^\circ < l < +80^\circ$ and $b < \pm 3^\circ$ are displayed in Figure 3. The Gaussian parameters fitted to these spectra are given in Table 1.

4. DISTRIBUTION OF ELDWIM IN THE INNER GALAXY

Kinematical distances to ELDWIM clouds were obtained from a Galactic rotation curve (Sofue et al. 2009) using the $V_{\text{LSR}}$ of H271α RLs. The distribution of these clouds in the plane ($b = 0^\circ$) of the Galaxy is shown in Figure 4. Due to observed $V_{\text{LSR}}$ of clouds above and below the plane there is a similar distribution in these regions as well. The width of the lines indicates an upper limit on the spread of gas along the line of sight. The FWHM of the hydrogen lines mostly lie within 20–60 km s$^{-1}$. The profiles also seem to lack pressure broadening (Brocklehurst & Leeman 1971; Shaver 1975) due to the absence of extended wings. All the profiles are compatible with a Gaussian fit. From this, one can deduce that the number density of electrons $n_e$ has an upper cutoff of 10 cm$^{-3}$ (Baddi 2011b; R. Baddi 2012, in preparation) in ELDWIM. At this density and frequency the pressure broadening contribution is $\sim 10$ km s$^{-1}$. The average error on the hydrogen line widths is contained within this.
Table 1
Gaussian Parameters for the Profiles in Figure 3

| Source | $T_L$ | $V_{LSR}$ | $\Delta V_{LSR}$ | $T_c$ | $D_c$ | Comments |
|--------|-------|-----------|-----------------|-------|-------|----------|
|        | $^\circ$ | (mK)      | (km s$^{-1}$)   | (km s$^{-1}$) | (K)   | (kpc)    |
| 78     | $+2$   | 83(20)    | $-138(3)$       | 26(7) | 297   | C        |
|        |        | 182(13)   | 0(2)            | 64(5) | 3.7/   | H        |
| 78     | 0      | 78(34)    | $-137(7)$       | 31(15)| 234   | C        |
|        | 155(29)| 2(4)      | 42(9)           |       | 3.5/   | H        |
| 78     | $-2$   | ...       | ...             | ...   | 104   | H        |
| 76     | $+2$   | ...       | ...             | ...   | 104   | ND       |
| 76     | 0      | 45(12)    | 0(6)            | 44(13)| 78    | 4.3/     |
| 76     | $-2$   | ...       | ...             | ...   | 66    | ND       |
| 74     | $+2$   | ...       | ...             | ...   | 91    | ND       |
| 74     | 0      | ...       | ...             | ...   | 140   | ND       |
| 74     | $-2$   | ...       | ...             | ...   | 84    | ND       |
| 72     | $+2$   | ...       | ...             | ...   | 28    | ND       |
| 72     | 0      | 40(10)    | 0(4)            | 32(9) | 84    | 5.4/     |
| 72     | $-2$   | ...       | ...             | ...   | 55    | ND       |
| 70     | $+2$   | ...       | ...             | ...   | 72    | ND       |
| 70     | 0      | ...       | ...             | ...   | 72    | ND       |
| 70     | $-2$   | ...       | ...             | ...   | 18    | ND       |
| 68     | $+2$   | ...       | ...             | ...   | 44    | ND       |
| 68     | 0      | ...       | ...             | ...   | 72    | ND       |
| 68     | $-2$   | ...       | ...             | ...   | 163   | ND       |
| 66     | $+2$   | ...       | ...             | ...   | 55    | ND       |
| 66     | 0      | ...       | ...             | ...   | 111   | ND       |
| 66     | $-2$   | ...       | ...             | ...   | 111   | ND       |
| 64     | $+2$   | ...       | ...             | ...   | 44    | ND       |
| 64     | 0      | ...       | ...             | ...   | 72    | ND       |
| 64     | $-2$   | ...       | ...             | ...   | 60    | ND       |
| 62     | $+2$   | ...       | ...             | ...   | 78    | ND       |
| 62     | 0      | ...       | ...             | ...   | 72    | ND       |
| 62     | $-2$   | ...       | ...             | ...   | 72    | ND       |
| 60     | $+2$   | ...       | ...             | ...   | 84    | ND       |
| 60     | 0      | 32(8)     | $-135(5)$       | 40(11)| 91    | 1.0/     |
|        |        | 37(7)     | 16(5)           | 56(12)|       | H        |
| 60     | $-2$   | ...       | ...             | ...   | 55    | ND       |
| 58     | $+2$   | ...       | ...             | ...   | 78    | ND       |
| 58     | 0      | ...       | ...             | ...   | 91    | ND       |
| 58     | $-2$   | ...       | ...             | ...   | 49    | ND       |
| 56     | $+2$   | ...       | ...             | ...   | 104   | ND       |
| 56     | 0      | ...       | ...             | ...   | 118   | ND       |
| 56     | $-2$   | ...       | ...             | ...   | 78    | ND       |
| 54     | $+2$   | ...       | ...             | ...   | 140   | ND       |
| 54     | 0      | ...       | ...             | ...   | 140   | ND       |
| 54     | $-2$   | ...       | ...             | ...   | 84    | ND       |
| 52     | $+2$   | ...       | ...             | ...   | 125   | ND       |
| 52     | 0      | ...       | ...             | ...   | 188   | ND       |
| 52     | $-2$   | ...       | ...             | ...   | 97    | ND       |
| 50     | $+2$   | ...       | ...             | ...   | 132   | ND       |
| 50     | 0      | 108(18)   | 68(3)           | 41(8) | 254   | 5.5/     |
| 50     | $-2$   | ...       | ...             | ...   | 206   | ND       |
| 48     | $+2$   | ...       | ...             | ...   | 111   | ND       |
| 48     | 0      | ...       | ...             | ...   | 234   | ND       |
| 48     | $-2$   | ...       | ...             | ...   | 38    | ND       |
| 46     | $+2$   | ...       | ...             | ...   | 125   | ND       |
| 46     | 0      | 112(26)   | 78(3)           | 28(7) | 275   | 5.9/     |
| 46     | $-2$   | ...       | ...             | ...   | 188   | ND       |
| 44     | $+2$   | ...       | ...             | ...   | 125   | ND       |
| 44     | 0      | ...       | ...             | ...   | 215   | ND       |
| 44     | $-2$   | ...       | ...             | ...   | 132   | ND       |
| 42     | $+2$   | ...       | ...             | ...   | 197   | ND       |
| 42     | 0      | ...       | ...             | ...   | 265   | ND       |
| 42     | $-2$   | ...       | ...             | ...   | 188   | ND       |
| 40     | $+2$   | ...       | ...             | ...   | 308   | ND       |
| 40     | 0      | ...       | ...             | ...   | 344   | ND       |
| 40     | $-2$   | ...       | ...             | ...   | 234   | ND       |
| 38     | $+2$   | 126(22)   | $-132(3)$       | 34(7) | 332   | C        |
|        |        | 106(28)   | 36(3)           | 21(6) | 2.0/   | H        |
Table 1
(Continued)

| Source | $T_L$ | $V_{LSR}$ | $\Delta V_{LSR}$ | $T_e$ | $D_e$ | Comments |
|-------|------|----------|----------------|------|------|----------|
|       | (mK) | (km s$^{-1}$) | (km s$^{-1}$) | (K)  | (kpc) |          |
| 38    | 0    | ...      | ...           | 482  |      | NLD      |
| 38    | $-2$ | ...      | ...           | 215  |      | NLD      |
| 36    | $+2$ | 75(15)   | $-132(4)$     | 40(10)| 206  | C        |
| 36    | 0    | 78(17)   | 95(4)         | 33(8) | 6.2$^a$ | H        |
| 36    | 0    | 69(12)   | $-107(6)$     | 66(13)| 320  | C        |
| 36    | $-2$ | 119(15)  | 65(3)         | 42(6) | 3.8$^a$ | H        |
| 34    | $+2$ | ...      | ...           | 197  |      | NLD      |
| 34    | 0    | 153(22)  | $-121(4)$     | 58(9) | 452  | C        |
| 34    | $-2$ | 131(18)  | 59(6)         | 84(13)| 3.5$^a$ | H        |
| 34    | $-2$ | ...      | ...           | 188  |      | NLD      |
| 32    | $+2$ | 92(15)   | 89(2)         | 27(5) | 180  | 5.1$^a$ | H        |
| 32    | 0    | 213(18)  | 90(2)         | 48(5) | 344  | 5.2$^a$ | H        |
| 32    | $-2$ | 150(50)  | 83(4)         | 25(10)| 357  | 4.8$^a$ | H        |
| 30    | $+2$ | 38(11)   | 81(7)         | 46(15)| 234  | 4.7$^a$ | H        |
| 30    | 0    | 325(35)  | 91(2)         | 46(6) | 452  | 5.2$^a$ | H        |
| 30    | $-2$ | 68(17)   | 87(4)         | 32(9) | 357  | 5.0$^a$ | H        |
| 28    | $+2$ | 111(26)  | 83(4)         | 35(9) | 297  | 4.8$^a$ | H        |
| 28    | 0    | 296(28)  | 39(... )      | 30(...)| 423  | 2.5$^a$ | H        |
| 28    | $-2$ | 65(17)   | 90(5)         | 37(11)| 308  | 5.1$^a$ | H        |
| 26    | $+2$ | 161(37)  | 86(3)         | 30(8) | 308  | 2.0$^a$ | H        |
| 26.5  | 0    | 92(26)   | $-70(4)$      | 30(10)| 500  | C        |
| 26    | $-2$ | 113(21)  | 86(4)         | 43(9) | 396  | 4.9$^a$ | H        |
| 24    | $+2$ | 122(22)  | 87(4)         | 41(9) | 382  | 5.0$^a$ | H        |
| 24    | 0    | 97(23)   | $-105(9)$     | 73(21)| 582  | C?       |
| 24    | $-2$ | 262(27)  | 82(3)         | 56(7) | 48$^a$ | H        |
| 24    | 0    | 75(17)   | 86(4)         | 39(10)| 308  | 5.0$^a$ | H        |
| 22    | $+2$ | 132(25)  | 65(5)         | 56(12)| 344  | 4.2$^a$ | H        |
| 22    | 0    | 180(35)  | 76(4)         | 45(10)| 618  | 4.6$^a$ | H        |
| 22    | $-2$ | 349(21)  | 98(... )      | 33(...)| 332  | NLD      |
| 20    | $+2$ | 147(37)  | 26(3)         | 27(8) | 396  | 2.1$^a$ | H        |
| 20    | 0    | 113(52)  | $-115(4)$     | 17(10)| 547  | C        |
| 20    | $-2$ | 188(52)  | 51(4)         | 46(9) | 3.7$^a$ | H        |
| 20    | $+2$ | 43(22)   | $-138(7)$     | 26(16)| 332  | C        |
| 18    | 0    | 87(14)   | 60(5)         | 70(13)| 4.1$^a$ | H        |
| 18    | 0    | 227(27)  | 28(2)         | 33(5) | 2.4$^a$ | H        |
| 18    | $-2$ | 110(33)  | $-115(10)$    | 69(24)| 564  | C        |
| 18    | 0    | 282(32)  | 44(4)         | 71(9) | 3.5$^a$ | H        |
| 16    | $+2$ | 66(14)   | 47(8)         | 77(19)| 320  | 3.6$^a$ | H        |
| 16    | 0    | 102(22)  | $-132(4)$     | 40(10)| 357  | C        |
| 16    | $-2$ | 179(33)  | 29(2)         | 34(5) | 2.7$^a$ | H        |
| 16    | 0    | 162(29)  | $-128(3)$     | 35(7) | 582  | C        |
| 14    | $+2$ | 217(31)  | $-151(2)$     | 29(6) | 382  | C        |
| 14    | 0    | 121(26)  | 32(4)         | 41(10)| 2.9$^a$ | H        |
| 14    | $+2$ | 108(26)  | 29(4)         | 34(9) | 357  | 2.9$^a$ | H        |
| 14    | 0    | 243(27)  | $-122(2)$     | 42(5) | 676  | C        |
| 14    | $-2$ | 448(27)  | 29(1)         | 41(3) | 2.9$^a$ | H        |
| 12    | $+2$ | 122(29)  | $-149(3)$     | 26(7) | 357  | C        |
| 12    | 0    | 94(25)   | 30(5)         | 36(11)| 3.0$^a$ | H        |
| 12    | $-2$ | 108(23)  | $-150(2)$     | 21(5) | 320  | C        |
| 12    | 0    | 178(28)  | $-126(4)$     | 47(9) | 564  | C        |
| 12    | 0    | 354(29)  | 32(2)         | 44(4) | 3.5$^a$ | H        |
| 10    | $+2$ | 53(20)   | $-146(11)$    | 58(25)| 396  | C        |
| 10    | 0    | 127(24)  | 25(4)         | 40(9) | 2.9$^a$ | H        |
| 10    | $+2$ | 69(42)   | $-142(6)$     | 18(13)| 382  | C        |
| 10    | 0    | 102(34)  | 20(5)         | 28(11)| 2.8$^a$ | H        |
| Source | $T_L$ | $V_{\text{LSR}}$ | $\Delta V_{\text{LSR}}$ | $T_e$ | $D_e$ | Comments |
|--------|-------|-----------------|-----------------|-------|-------|----------|
|        | (mK)  | (km s$^{-1}$)   | (km s$^{-1}$)   | (K)   | (kpc) |          |
| 10     | 172(26) | $-126(3)$       | 43(8)           | 656   |       | C        |
|        | 381(26) | 21(1)           | 44(3)           |       | 2.9$^{a}$ | H        |
| 10     | 65(21)  | $-143(8)$       | 49(18)          | 369   |       | C        |
|        | 192(25) | 23(2)           | 33(5)           |       | 3.1$^{a}$ | H        |
| 8      | 80(33)  | 17(4)           | 21(10)          | 308   |       | 2.9$^{a}$ | H        |
|        | 148(19) | $-139(4)$       | 63(9)           | 618   |       | C        |
|        | 328(25) | 19(1)           | 36(3)           |       | 3.1$^{a}$ | H        |
| 8      | 85(36)  | $-142(4)$       | 20(10)          | 396   |       | C        |
|        | 153(33) | 17(2)           | 23(6)           |       | 2.9$^{a}$ | H        |
| 6      | 44(49)  | $-134(9)$       | 16(21)          | 344   |       | C        |
|        | 70(49)  | 11(6)           | 16(13)          |       | 2.6$^{a}$ | H        |
| 6      | 268(39) | $-145(4)$       | 58(10)          | 738   |       | C        |
|        | 441(53) | 18(2)           | 31(4)           |       | 3.6$^{a}$ | H        |
| 6      | 105(24) | $-148(5)$       | 48(13)          | 369   |       | C        |
| 4      | 112(33) | 9(4)            | 30(10)          | 332   |       | 3.0$^{a}$ | H        |
| 4      | 164(34) | $-141(4)$       | 37(9)           | 637   |       | C        |
| 4      | 240(39) | 9(2)            | 29(5)           |       | 3.0$^{a}$ | H        |
| 4      | 68(28)  | $-145(3)$       | 16(8)           | 297   |       | C        |
|        | 97(27)  | 15(2)           | 18(6)           |       | 4.1$^{a}$ | H        |
| 2      | 223(52) | $-151(2)$       | 22(6)           | 656   |       | C        |
| 2      | 270(51) | 0(2)            | 22(5)           |       | [1.5]$^{a}$ | H        |
| 2      | 94(23)  | 20(6)           | 48(13)          | 344   |       | 6.2$^{a}$ | H        |
| 0      | 79(28)  | $-142(7)$       | 42(17)          | 437   |       | C        |
| 0      | 197(33) | 12(3)           | 31(6)           |       |       |          |
| 0      | 345(74) | $-149(2)$       | 20(5)           | 1150  |       | C        |
| 0      | 680(149)| 0(2)            | 24(5)           |       |       |          |
| 0      | 140(57) | 33(22)          | 42(42)          |       |       |          |
| 0      | 122(25) | $-145(5)$       | 53(13)          | 482   |       | C        |
| 0      | 148(30) | 5(4)            | 37(9)           |       |       |          |
| 0      | 259     | 0(3)            | 37(7)           |       | [2]$^{a}$ | H        |
| 0      | 94(24)  | $-158(3)$       | 25(7)           | 275   |       | C        |
| 0      | 114(20) | 0(3)            | 35(7)           |       | [2]$^{a}$ | H        |
| 0      | 147(60) | 0(6)            | 29(14)          | 357   |       | [1.8]$^{a}$ | H        |
| 0      | 188(42) | $-153(3)$       | 24(6)           | 514   |       | C        |
| 0      | 233(33) | 0(3)            | 37(6)           |       | [1.0]$^{a}$ | H        |
| 0      | 90(28)  | $-154(3)$       | 22(8)           | 332   |       | C        |
| 0      | 129(27) | 0(2)            | 24(6)           |       | [1.0]$^{a}$ | H        |
| 0      | 71(30)  | $-121(7)$       | 36(17)          | 357   |       | C        |
| 0      | 169(24) | 0(4)            | 54(9)           |       | [1.0]$^{a}$ | H        |
| 0      | 71(36)  | $-158(9)$       | 36(21)          | 467   |       | C        |
| 0      | 203(44) | 0(3)            | 24(6)           |       | [1.0]$^{a}$ | H        |
| 0      | 100(13) | 0(5)            | 72(11)          | 188   |       | [1.2]$^{a}$ | H        |
| 0      | 147(55) | 0(7)            | 36(15)          | 265   |       | [1.4]$^{a}$ | H        |
| 0      | 69(29)  | $-159(4)$       | 20(10)          | 344   |       | C        |
| 0      | 183(22) | $-9(2)$         | 33(5)           |       | 2.0$^{a}$ | H        |
| 0      | 72(23)  | $-119(6)$       | 41(15)          | 215   |       | C?        |
| 0      | 109(20) | $-11(5)$        | 51(11)          |       | 2.0$^{a}$ | H        |
| 0      | 137(46) | $-10(6)$        | 35(14)          | 215   |       | [2.3]$^{a}$ | H        |
| 0      | 106(36) | $-15(5)$        | 27(11)          | 344   |       | 2.3$^{a}$ | H        |
| 0      | 131(36) | $-10(5)$        | 37(12)          | 254   |       | [2.3]$^{a}$ | H        |
| 0      | 79(15)  | $-13(5)$        | 51(11)          | 180   |       | 1.7$^{a}$ | H        |
| 0      | 104(35) | $-10(5)$        | 32(12)          | 188   |       | [1.3]$^{a}$ | H        |
Table 1 (Continued)

| Source | TL | V$_{LSR}$ | ΔV$_{LSR}$ | T$_c$ | D$_c$ | Comments |
|--------|----|-----------|------------|-------|--------|-----------|
| 0      | 0  | 135(45)   | -154(2)    | 12(4) | 332    | 2.7$^a$ H |
| -18    | -2 | 113(31)   | -33(3)     | 24(8) | 163    | ND        |
| -20    | +2 | ...       | ...        | ...   | 206    | NLD       |
| -20    | 0  | 78(33)    | -40(9)     | 41(21)| 320    | 3.0$^a$ H |
| -20    | -2 | ...       | ...        | ...   | 224    | NLD       |
| -22    | +2 | ...       | ...        | ...   | 171    | ND        |
| -22    | 0  | ...       | ...        | ...   | 369    | NLD       |
| -22    | -2 | 50(11)    | -29(5)     | 46(11)| 155    | 2.1$^a$ H |
| -24    | +2 | ...       | ...        | ...   | 140    | NLD       |
| -24    | 0  | ...       | ...        | ...   | 254    | NLD       |
| -24    | -2 | 25(7)     | -33(6)     | 44(15)| 78     | 2.3$^a$ H |
| -26    | +2 | ...       | ...        | ...   | 207    | NLD       |
| -26    | 0  | 175(45)   | -56(7)     | 59(17)| 301    | 3.6$^a$ H |
| -26    | -2 | 112(95)   | -60(16)    | 32(39)| 191    | 3.8$^a$ H |
| -26    | -2 | ...       | ...        | ...   | 33(56) | 2.2$^a$ H |
| -28    | +2 | ...       | ...        | ...   | 125    | NLD       |
| -28    | 0  | 108(29)   | -55(7)     | 56(17)| 215    | 3.5$^a$ H |
| -28    | -2 | 90(33)    | -77(5)     | 30(13)| 147    | 4.6$^a$ H |
| -30    | +2 | ...       | ...        | ...   | 125    | NLD       |
| -30    | 0  | 139(28)   | -50(2)     | 23(5)| 225    | 3.0$^a$ H |
| -30    | -2 | ...       | ...        | ...   | 132    | NLD       |

Notes. Comments—C: carbon line; H: hydrogen line; ND: no data; NLD: no line detection. D$_c$ flags—f: far; n: near; m: distance for maximum V$_{LSR}$ possible from rotation curve. Positions with errors in V$_{LSR}$ greater than 50% have been provided with an upper limit between bars taking into account the full value of the errors, which are given in parentheses, especially near l = 0$^\circ$.

Figure 4. Distribution of ELDWIM clouds in the plane (b = 0$^\circ$) of the Galaxy. The origin marks the solar system S and GC is the Galactic Center. Ω$_{ORT}$ is the beam of ORT. The red circles mark the center of line origin obtained from the fitted V$_{LSR}$. The length of the line through these circles is the FWHM converted to distance, indicating an upper limit on the spread of the gas. Due to observed V$_{LSR}$ the clouds above (b = +2$^\circ$) and below (b = −2$^\circ$) the plane follow a similar distribution. (A color version of this figure is available in the online journal.)

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REFERENCES

Anantharamaiah, K. R. 1985a, JA&A, 6, 177
Anantharamaiah, K. R. 1985b, JA&A, 6, 203
Anantharamaiah, K. R. 1986, JA&A, 7, 131
Baddi, R. 2011a, AJ, 141, 190
Baddi, R. 2011b, AJ, 141, 154
Batty, M. J. 1976, Aust. J. Phys., 29, 419
Brocklehurst, M., & Leeman, S. 1971, Astrophys. Lett., 9, 35
Dravskikh, A. F., Dravskikh, Z. V., Kolbasov, V. A., et al. 1965, Dok. Akad. Nauk SSSR 163, 332 (English Translation: 1966, Sov. Phys. Dokl. 10, 627)
Egorova, T. M., & Ryzkov, N. F. 1960, Izv. Gl. Astrofiz. Obs., 21, 174
Goldberg, L., & Dupree, A. K. 1967, Nature, 215, 41
Gottesman, S. T., & Gordon, M. A. 1970, ApJ, 162, L93
Lilley, A. E., Palmer, P., Penfield, H., & Zuckerman, B. 1966, Nature, 211, 419
Prabu, T. 2010, PhD thesis, Indian Institute of Science, Bangalore
Roshi, D. A., & Anantharamaiah, K. R. 2000, ApJ, 557, 226
Roshi, D. A., & Anantharamaiah, K. R. 2001a, JA&A, 22, 81
Roshi, D. A., & Anantharamaiah, K. R. 2001b, ApJ, 557, 226
Shaver, P. A. 1975, Pramana, 5, 1
Sofue, Y., Honma, M., & Onodera, T. 2009, PASJ, 61, 227
Swarup, G., Sarma, N. V. G., Joshi, M. N., et al. 1971, Nat., Phys. Sci., 230, 185