CHAPTER 7

DISTRIBUTION OF THE LOW DENSITY GAS AND THE ORIGIN OF THE GALACTIC RIDGE RECOMBINATION LINES

In the previous chapter it was shown from an analysis of the observed intensity and width of the H272α lines, that the ionized regions responsible have electron densities of 1-10 cm^{-3}, electron temperatures of 3000-8000K and that they extend over 50-300 pc along the line of sight. Towards HII regions we identified this gas with extended low density envelopes surrounding them In this chapter we first derive the distribution of the low density gas implied by the observed line velocities. The derived distribution is compared to those of neutral hydrogen, molecular clouds and conventional HII regions. We then discuss the origin of the galactic ridge recombination lines and show that they can be accounted for by the low density envelopes of conventional HII regions which are prominent in the radio continuum maps of the galaxy and which are widely studied using high frequency recombination lines.

7.1 THE LONGITUDE-VELOCITY DIAGRAM

The l-v diagram is an indicator of the distribution of the gas in the galactic disk. Such a diagram for the observed H272α lines was briefly discussed in Section 5.7.4.

The l-v diagram is a true indicator of the distribution of a species only if observations are made at fairly uniform intervals over the entire longitude range of interest. The data obtained in the present study does not strictly conform to this criterion. Even so, as a sufficiently large number of observations have been made over the longitude range 0° - 60°, the l-v diagram can give a reasonable indication of the distribution of the gas responsible. In any case, the available data is sufficient for a comparison with the distribution of other species like neutral hydrogen, molecular clouds and conventional HII regions.

In Figure 7.1 we have shown the velocity extent of the 272α line emission at different longitudes superposed on an l-v diagram for the 1664 recombination lines observed by Lockman (1976). The 166α observations are fairly uniformly spaced and cover more or less the same longitude extent as the H272α survey. It is clear from this figure that the distribution of the gas responsible for the 272α lines is similar to that seen in 166α. Some of the smoothness in the 1664 distribution is, (as noted by Lockman 1976), a result' of the coarse sampling of the galactic plane in the observation. In Fig 7.2, in addition to the distribution of 166α and 272α line emission, we have marked with crosses the location of HII regions observed in the H110α survey of Downes et al (1980). The crosses indicate what we shall call conventional HII regions. The H110α survey is more complete in the sense that Downes et al (1980) have observed all the continuum sources in the range $\ell = 0^\circ$ to 60° and $b = \pm 1^\circ$, having flux densities >1 Jy at 5 GHz. The distribution of these sources is again very similar to that of the ionized gas from which the 1664 and the 2724 lines are observed.

Most of the H110α sources are high emission measure objects (10^4 - 10^6 pc cm^{-6}) and would be nearly optically thick at the 2724 frequency. For this reason and because of the large beam dilution due to their small angular diameter (few arcminutes), they produce practically no detectable 272α line. On the other hand, they are very easily detected in 166α line observations, such as those of Lockman (1976) and Hart and Pedlar (1976). It is therefore remarkable that the l-v diagram for the observed 272α lines agrees so well with those for the 166α and 110α lines. The obvious conclusion is therefore that the low density gas responsible for the 272α line emission is associated with the HII regions seen in the H110α survey.

The distribution of HII regions with their attendant low density gas is also similar to that of molecular clouds seen in the 2.6mm carbon monoxide lines. In figure 7.3 we have

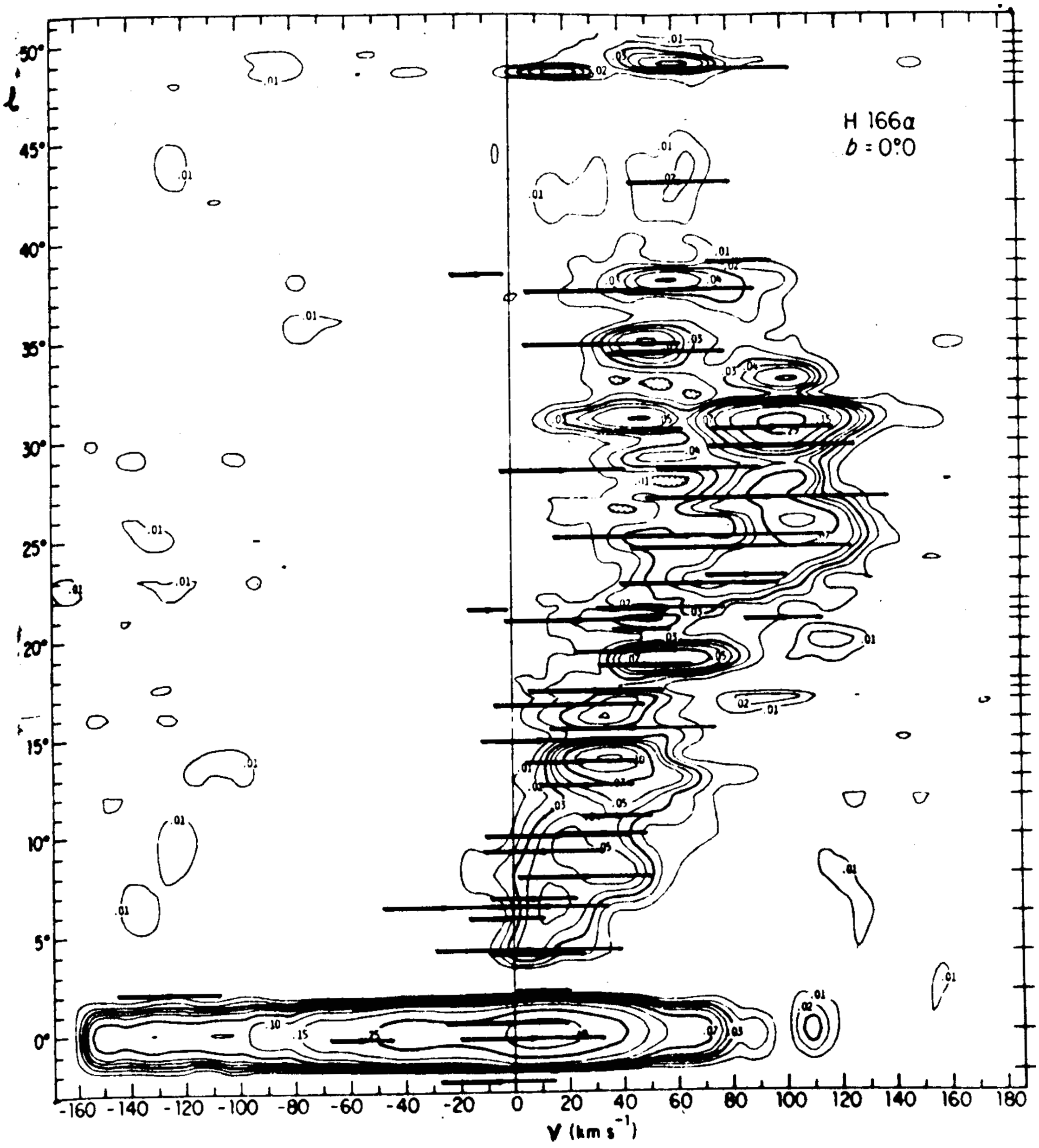

Fig. 7.1 l–v diagram of observed H272α lines superposed on that of H166α lines observed by Lockman (1976). The horizontal lines represent the half power width of H272α lines. The contours are for the H166 lines.

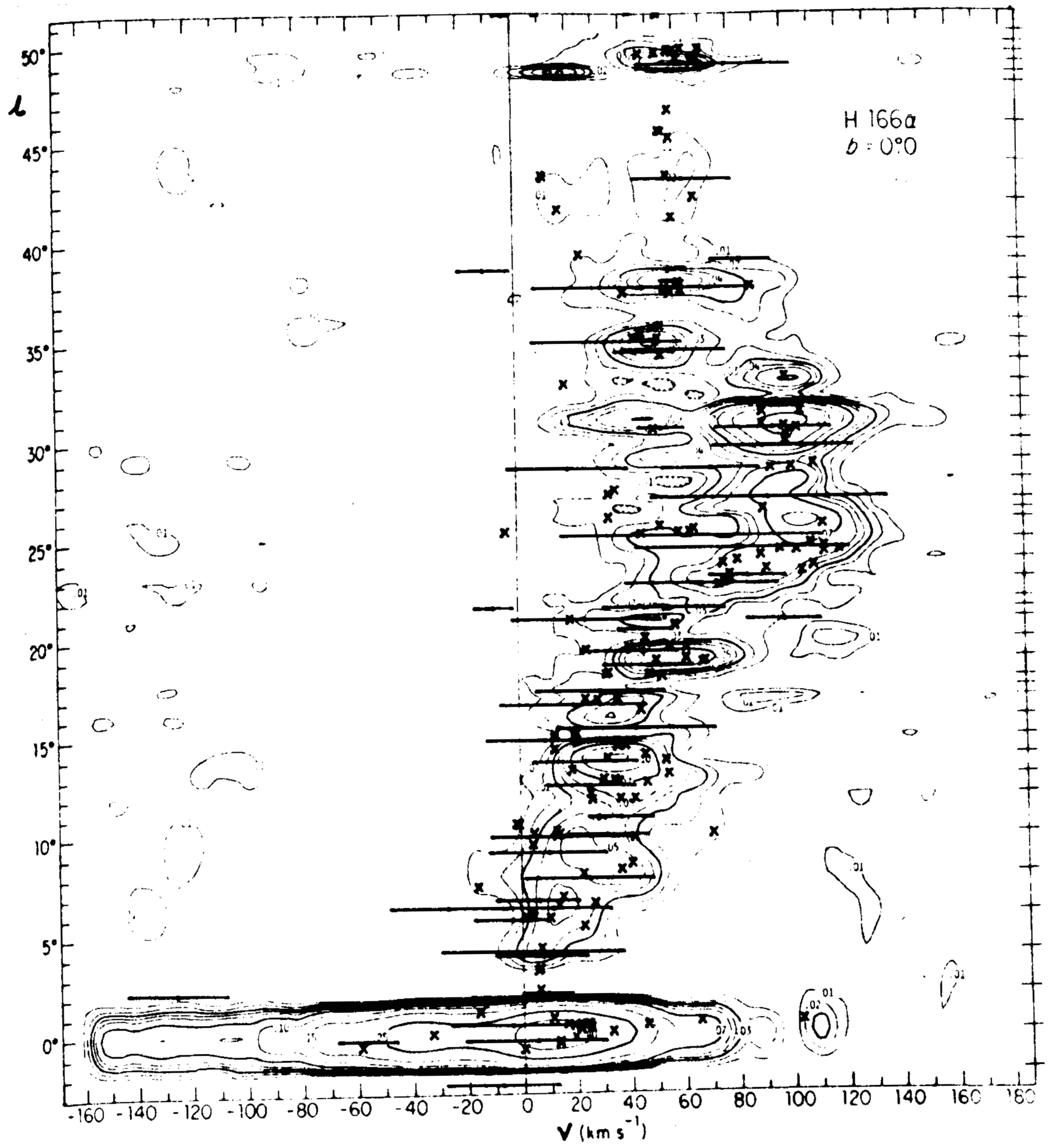

Fig. 7.2 Positions of H110α sources (Downes et. al. 1980). marked (crosses) on a l-v diagram of H166α (Lockman 1976). The horizontal lines indicate the extent of the H272α lines observed in this study.

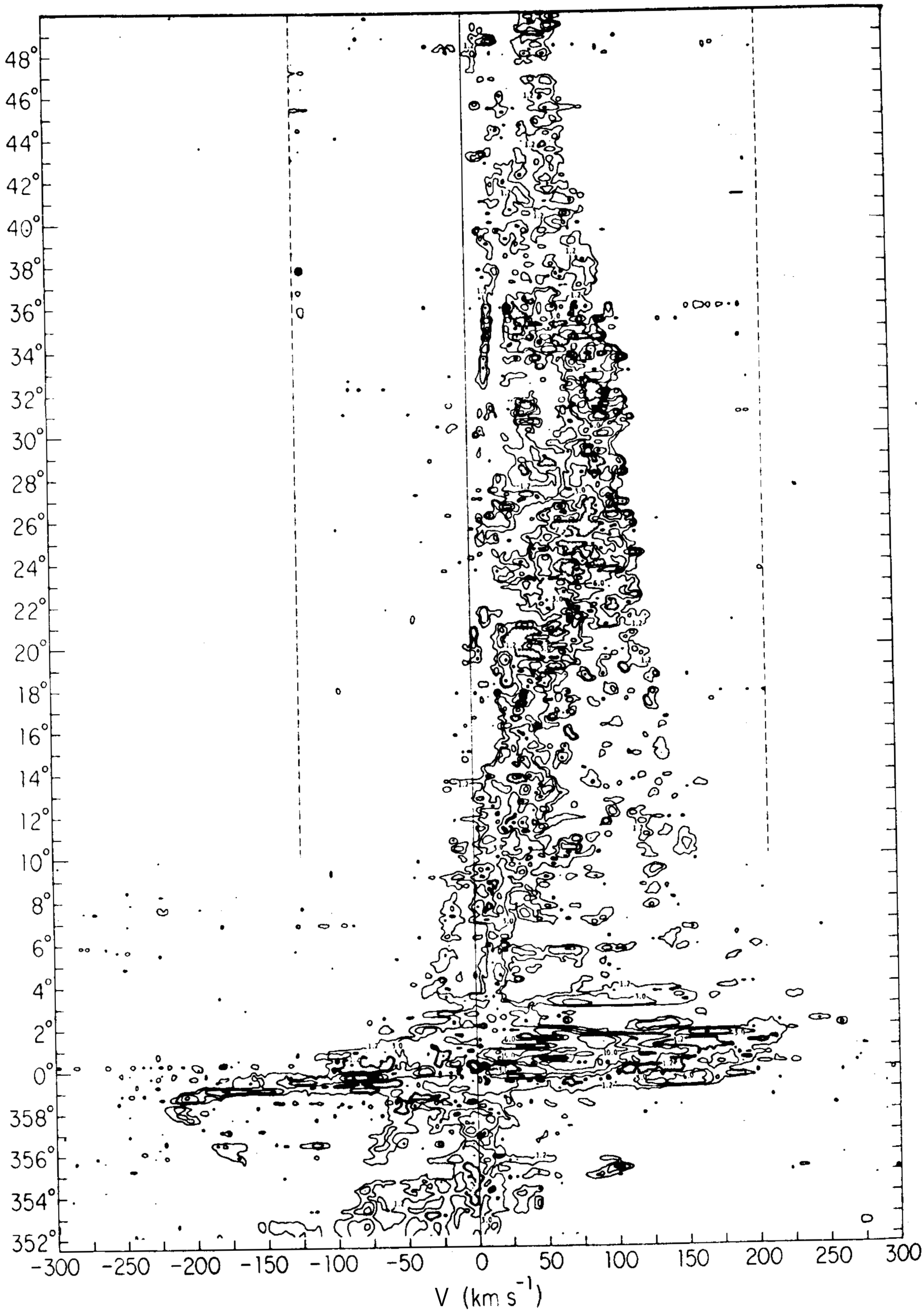

Fig. 7.3 l–v diagram of CO emission which indicates the distribution of molecular clouds. Taken from Burton and Gordon (1978).

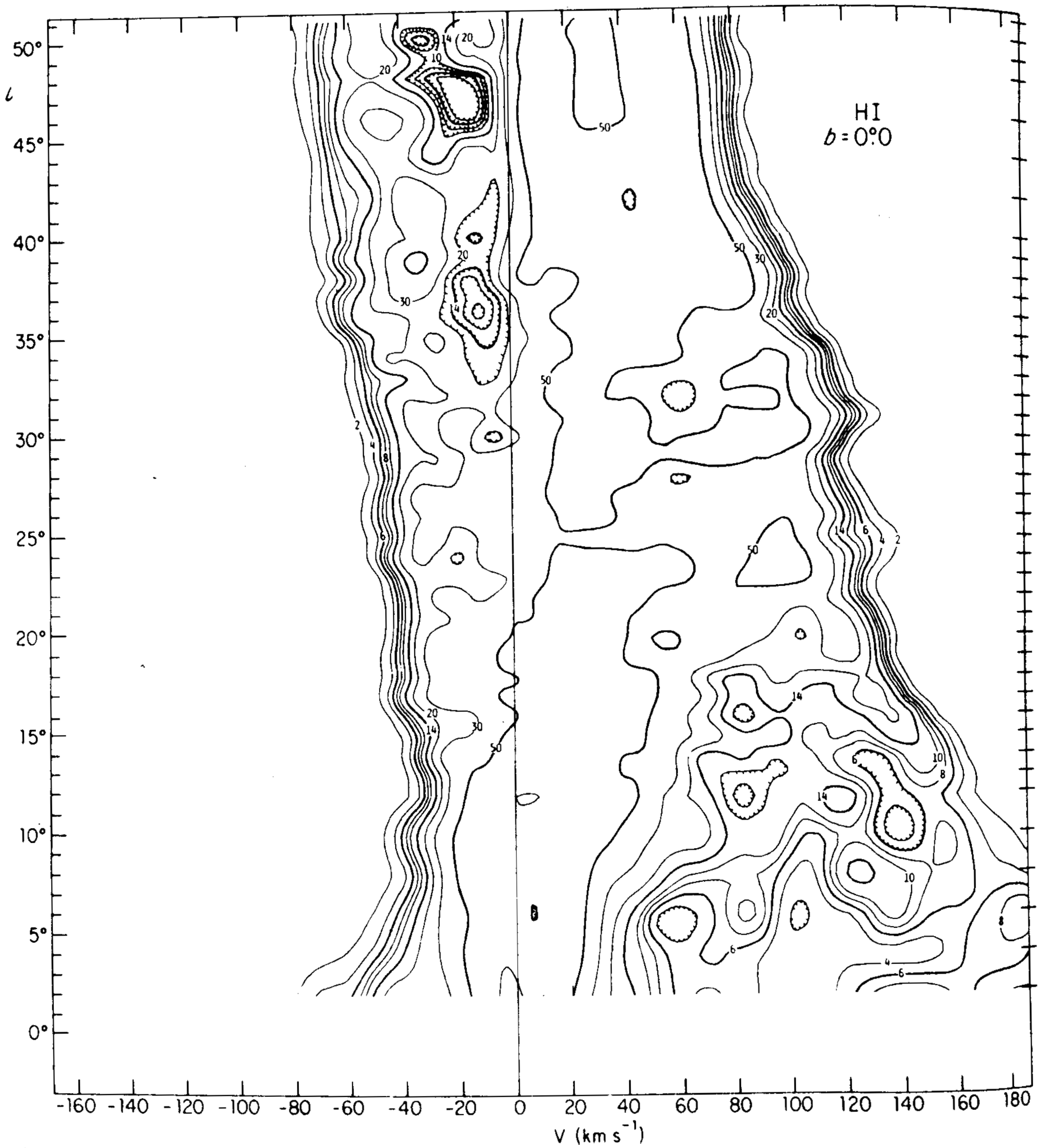

Fig. 7.4 l-v diagram of HI (21 cm) emission taken from Lockman (1976).

reproduced the l-v diagram for the CO emission taken from Burton and Gordon (1978). It can be seen that this distribution has many similarities with that of HII regions shown in Fig. 7.2. This is to be expected since giant molecular clouds which are traced by their CO emission, are believed to be the birth sites of stars (see for example Lada 1980). Young and hot stars which are born, will subsequently ionize their surroundings creating HII regions.

On the other hand, the distribution of neutral hydrogen seen in the 21cm HI line is quite different from those of molecular clouds, HII regions and their associated low density gas. Figure 7.4 taken from Lockman (1976) shows the distribution of HI in a l-v diagram Neutral hydrogen occupies a much larger region in this diagram The extension to negative velocities indicates that the gas extends well beyond the solar circle.

7.2 DISTRIBUTION AS A FUNCTION OF GALACTOCENTRIC DISTANCE

The l-v diagrams presented in the previous section are only qualitative indicators of the distribution of the gas in the galactic disk. The longitude velocity distribution should be combined with a model of galactic rotation to get a quantitative picture.

The distribution of the low density gas seen in the 272α survey, as a function of distance from the galactic centre, was obtained using the Schmidt model of galactic rotation (Schmidt 1965) as follows.

For pure circular rotation around the centre of the galaxy, the radial velocity V_r of an object at a distance R from the galactic centre is given by

$$V_r = R_0 \left[\omega(R) - \omega(R_0) \right] \sin l \cos b \qquad (7.1)$$

where $\omega(R)$ is the angular velocity of the object and $\omega(R_0)$ that of the Sun around the galactic centre given by the Schmidt (1965) rotation curve. l and b are the galactic longitude and latitude of the object and R_0 is the distance from the Sun to the galactic centre.

We have used the following analytical approximations to the Schmidt rotation curve given by Burton (1971)

$$R\,\omega(R) = 250 + 4{\cdot}05(10-R) - 1{\cdot}62\,(10-R)^2 \quad ;\text{for } 4\,\text{kpc} < R < 10\,\text{kpc}$$

$$R\,\omega(R) = 885{\cdot}44 \times R^{-1/2} - 30000\,R^{-3} \quad ;\text{ for } 10\,\text{kpc} < R < 14\,\text{kpc} \qquad (7{\cdot}2)$$

For $R < 4$ kpc we have used the rotation curve given by Simonson and Mader (1973).

For a given longitude, the ionized gas present at a distance R from the galactic centre will contribute to the observed spectrum at a velocity given by Equation. (7.1 The ionized gas present along a ring of radius R ($< R_0$) will contribute to all the spectra taken up to a maximum longitude given by

$$|\quad| = \sin^{-1}(R/R_0) \qquad (7{\cdot}3)$$

For $R > R_0$ the ionized gas will be observed at all longitudes.

We have computed the average contribution to the line temperature of the gas present at a given galactocentric radius R in all the observed spectra using

$$\left\langle T_L \frac{dV_r}{dr} \right\rangle_R = \frac{\sum T_L(l, V_r) \left| \frac{dV_r}{dr} \right|}{N} \qquad (7{\cdot}4)$$

The summation is made over all the N observed longitudes upto a maximum of l_{max} given by eqn. (7.3). r is either the far or the near distance of the ring from the Sun, at a longitude l . The gradient of velocity $\frac{dV_r}{dr}$ was calculated using Eqns. (7.1) and (7.2). It is necessary to apply a weighting factor of (dV_r/dr) since depending on the velocity gradient the contribution at a given velocity can come from gas distributed over a path length of $dV_r\,(dV_r/dr)^{-1}$ along the line of sight.

The quantity computed in equation (7.4) will be proportional to the total amount of line emitting gas present at a distance R from the galactic centre and sampled by the observations. This quantity for the observed 272α lines plotted as a function of R is shown in Fig. 7.5 in the form of a histogram

As seen in this figure, the distribution of the ionized regions responsible for the observed 272α lines is confined to galactocentric centric radii R 10 kpc. The peak of the distribution occurs at ∼ 5.5 kpc, and most of the gas is found between 4 kpc and 8 kpc. Inside of 4 kpc (where we have used the rotation curve. of Simonson and Mader 1973), large non-circular velocities are known to be prevalent, and therefore the implied distribution for this range is not reliable.

The actual distribution of the gas will in fact be narrower than suggested by Fig. 7.5. This is because in the above calculation we have implicitly attributed all of the observed velocity extent of the line emission to galactic rotation. The intrinsic width of the lines arising from thermal motions and turbulence has not been taken into account. This will result in a smearing of the distribution.

In figure 7.6 we have reproduced the distribution computed in a similar way by Lockman (1976) from his 166α and 21 cm HI line observations. A comparison of figure 7.5 and 7.6 shows that the 166α and 272α observations have sampled ionized regions which are distributed in a similar way in the galactic disk. Both the derived distributions show that this ionized gas is most abundant between galactocentric radii 4 and 8 kpc. On the other hand neutral hydrogen is distributed almost uniformly over a much larger range and extends out to R >14 kpc.

We have computed the distribution of conventional HII regions from the observed line parameters in the $H110\alpha$ survey of Downes et al (1980), using the method described above. The result is shown in Figure 7.7. Again we see that the 272α line emitting regions are distributed similar to conventional HII

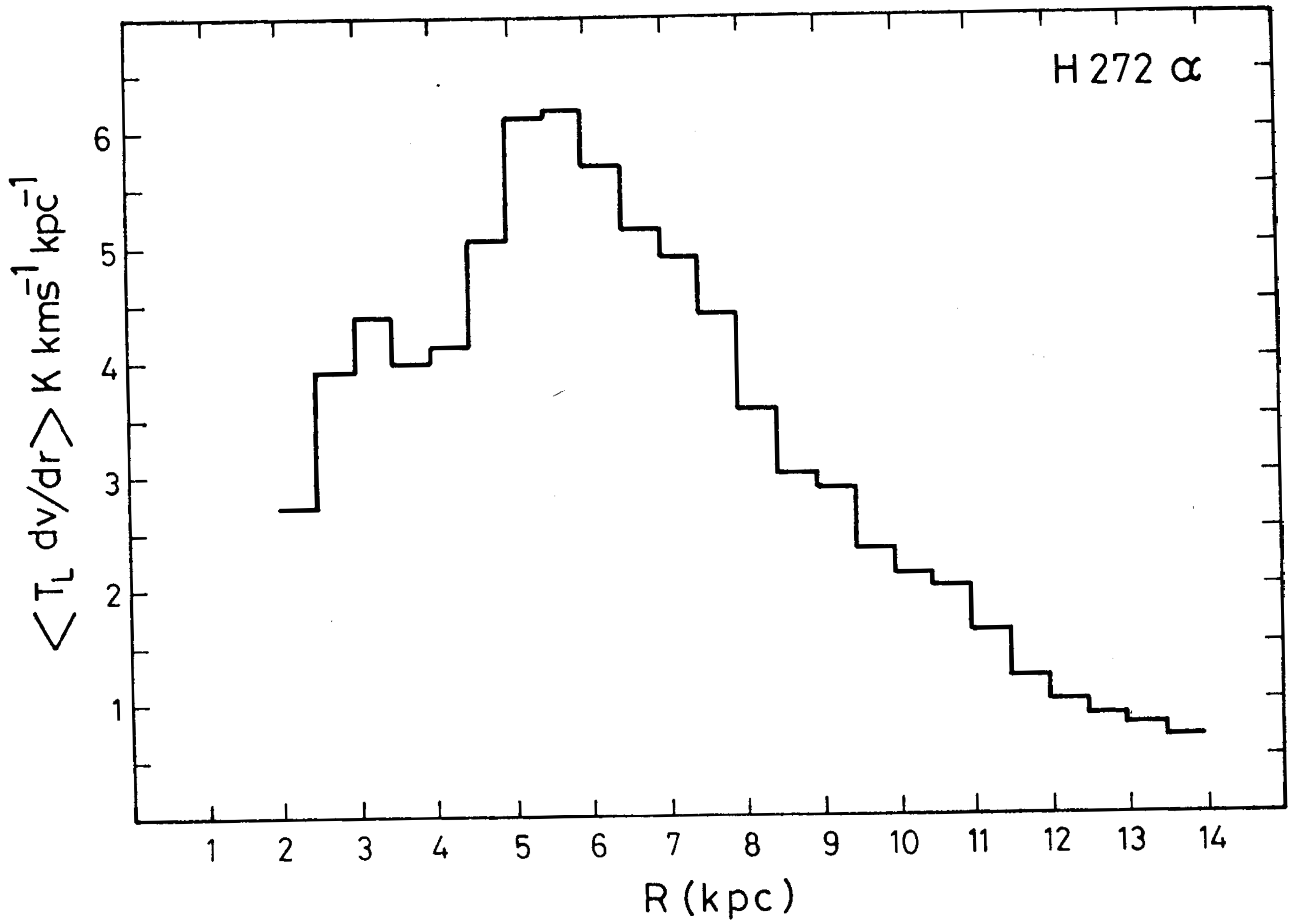

Fig. 7.5 Average H272α line emission as a function of distance from the galactic centre.

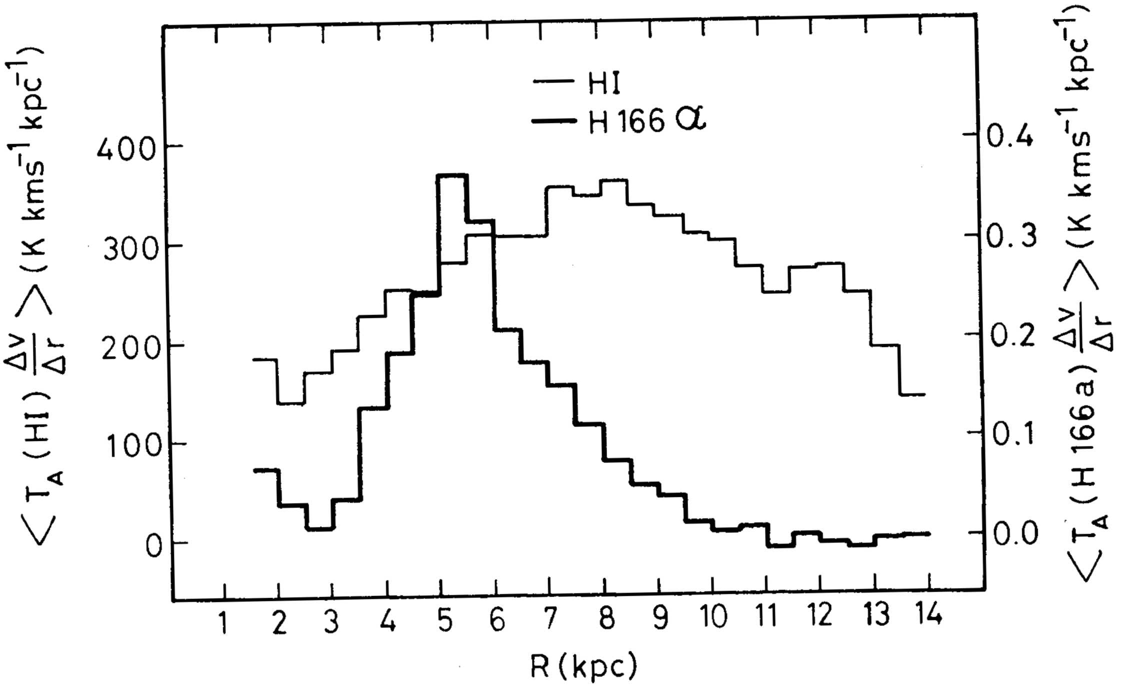

Fig. 7.6 Average H166α and HI emission as a function of galactocentric distance (taken from Lockman, 1976).

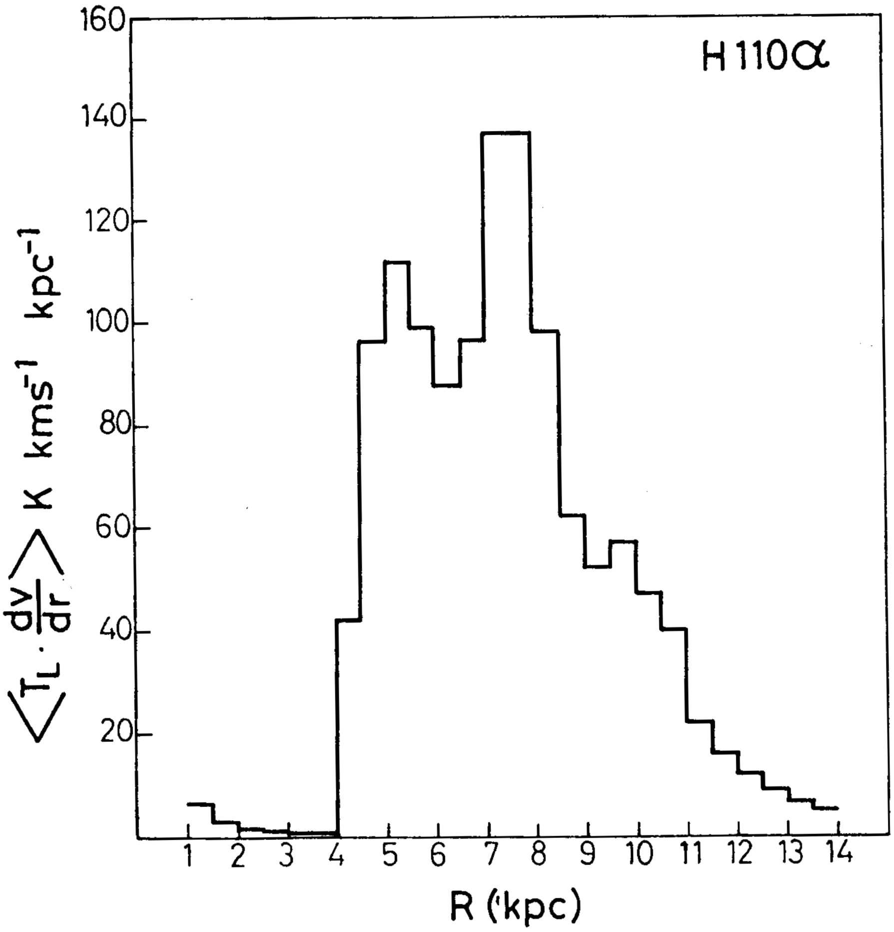

Fig. 7.7 Distribution of average H110α emission as a function of distance from the galactic centre calculated from the survey of Downes et.al. (1980).

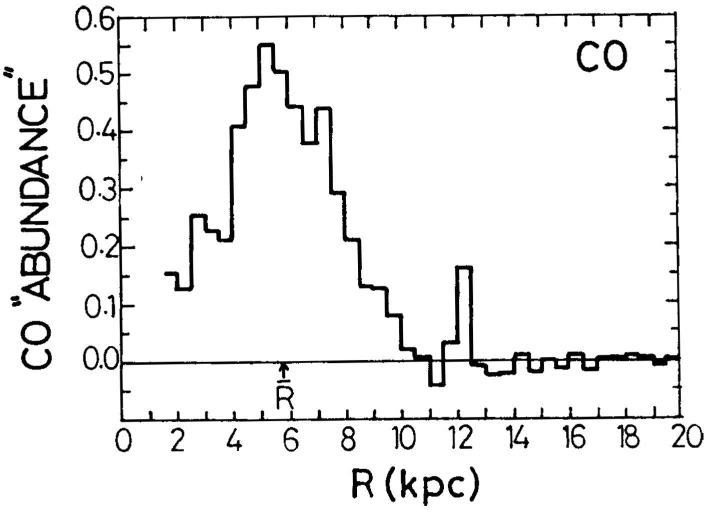

Fig. 7.8 Abundance of molecular gas as a function of galactocentric distance, as seen in their CO emission (taken from Burton et.al. 1975).

regions. Both of them show a peak in their distribution between 4 kpc and 8 kpc from the galactic centre. As expected from the comparison of the l-v diagrams, the molecular clouds seen by their CO emission also show a similar distribution in this range. This can be seen in Fig. 7.8 which is reproduced from Burton et al (1975).

7.3 ORIGIN OF THE GALACTIC RIDGE RECOMBINATION LINES

From the analysis in the previous chapter we have shown that the ionized regions, emitting the observed 272α recombination lines in the direction of blank areas in the galactic plane and SNRs, have electron densities of 1-10 cm^{-3}, electron temperatures higher than a few thousand degrees but less than about 8000K and that they extend over 50 - 150 pc along the line of sight. Similar low densities and path lengths of 50-300 pc were inferred from the analysis of lines observed towards conventional HII regions. The agreement in velocities of the 272α lines and those of higher frequency lines (mostly H110α) have suggested that the low density gas responsible for the low frequency line is associated with the dense HII regions from which the H110α lines are observed. We have attributed the low density gas to extended outer envelopes of the conventional HII regions. The parameters obtained towards HII regions indicate the densities and sizes of these envelopes. Further we have argued that the temperature of the envelopes cannot be very different from that of the high density gas in the core.

The lines observed towards blank regions and SNRs were identified, in the previous chapter, with the galactic ridge recombination lines observed at centimeter wavelengths (Gottesman and Gordon 1970, Gordon and Cato 1972, Mathews èt al 1973, Jackson and Kerr 1975). It was also shown there that the conventional HII regions which are prominent in the radio continuum cannot produce the 272α lines observed in their directions because of pressure broadening, optical depth and beam dilution. Therefore at this freq'uency, the lines observed towards HII regions can also be identified with galactic ridge recombination lines. In other words, towards any of these directions (i.e. blank regions, SNRs or HII regions) there are no discrete continuum sources which can produce the observed 272α line.

The parameters derived for the gas responsible for the blank region and SNR lines are very similar to those derived for the envelopes of HII regions. We therefore suggest that most (and probably all) of the observed galactic ridge recombination lines come from the extended low density outer envelopes of conventional HII regions. The similarity of the distributions of conventional HII regions and low density gas in the l-v diagrams presented in the previous section and the similarity of their distribution as a function of distance from the galactic centre lends support to this hypothesis.

There is also a theoretical justification for expecting low density gas to be associated with many HII regions. As noted in the previous section, most of the HII regions are associated with molecular clouds (see for example Israel 1978). These clouds are also believed to be the birth sites of stars. Observations of CO and associated recombination lines have suggested that massive stars are formed at the edges of giant molecular clouds (cf. Lada 1980). Such massive stars will produce HII regions which are like 'blisters' on the parent molecular cloud (Israel 1978). The HII region so produced will not be in pressure equilibrium with its surroundings, namely the interstellar medium This will result in outflow of ionized gas from the HII regions into the adjacent interstellar medium This phenomenon, now known in the literature as 'Champagne Flow', has been studied using theoretical models by Tenorio-Tagle et al' (1979) and Bodenheimer et al (1979). A review of champagne flow and related matters can be found in Tenorio-Tagle (1982). The models of champagne flow predict that there will be a rapid decrease in the mean electron density as one moves away from the HII region into the interstellar medium This will result in a diffuse low density partial envelope for the HII region. When there are a number of HII regions on the edges of the molecular cloud, this phenomenon will result in a low density gas envelope surrounding the entire molecular cloud. Harten and Felli (1982) report observational evidence for radio emission to be coming from increasingly more diffuse structure for HII regions with lower densities.

The sizes of the low density envelopes (derived in the previous chapter) are in the range of 50-300 pc. In the longitude range $\ell \lesssim 40^\circ$ where galactic ridge lines are 'seen, the distances to conventional HII regions range from 1 kpc to $\sim$17 kpc (see Downes et al 1980). The number of HII regions at far and near kinematic distances are about equal. Assuming an average distance of 9 kpc to these HII regions and an average size of 100 pc for their outer envelopes we see that the latter have angular sizes of $\sim 0\overset{\circ}{.}6$. An examination of the 5 GHz high resolution continuum map of Altenhoff et al (1978) reveals that the angular separation between prominent HII regions is on the average $\sim 0\overset{\circ}{.}5$ up to a longitude of 40°. The separation between somewhat weaker HII regions which still appear as discrete sources at 5 GHz is much less ($\sim 0\overset{\circ}{.}1$). Given this angular separation, and the angular sizes for the envelopes of $\sim 0\overset{\circ}{.}6$, we see that the outer low density envelopes of these HII regions will interesect practically every line of sight in this longitude range

The total number of discrete sources in the 5 GHz survey of Altenhoff et al (1978) over 80 square degrees of the galactic plane in the range $\ell \simeq 0^\circ$ to 40° and $b = \pm 1^\circ$ is $>$900. Allowing for 100 of them to be non-thermal sources there are in all more than 800 HII regions, strong and weak, in this area. This will amount to an average of 10 HII regions per square degree in this region. The density of sources in the range $b = \pm 0\overset{\circ}{.}5$ will be a factor of 3-4 higher since most of the sources are distributed over this narrower latitude range. The angular diameter of these sources range from a fraction of a minute of arc to several minutes of arc. Taking an average of 2 arcminutes for the diameter, we find that the discrete HII regions fill about 1/30th of the total area in the galactic plane from $\ell = 0^\circ$ to 40°, $b = \pm 0\overset{\circ}{.}5$. Therefore, if the extent of the low density envelopes are about 30 times that of the cores of the HII regions then this entire area will be covered by the low density gas. The sizes of conventional HII regions are in the range of 1 - 10 pc whereas the sizes derived for the low density envelopes are in the range 50 - 300 pc. Clearly the envelopes will intersect practically every line of sight in this area of the galactic plane. These low density envelopes can therefore give rise to most of the observed galactic ridge recombination lines.

Lockman (1979) has analysed the distribution of HII regions in the inner galaxy and concluded that they have a scale height ($z_{\frac{1}{2}}$) of 33 pc. If some of these HII regions have envelopes of 50-300 pc then the scale height of the low density gas will be a factor of 2 - 3 larger which is consistent with the 70-80 pc derived by Lockman (1976) and Hart and Pedlar (1976) from the latitude extent of the 166α line emission.

An examination of the 5 GHz map of Altenhoff et al (1978) shows that there is an extended background radiation (see for example Fig. 5.2) over which the discrete sources are superposed. The outer contours of emission do not break all the way upto $\ell = 40^\circ$. Most of this background emission must therefore be coming from the extended low density envelopes of the HII regions which are numerous in this range. The background emission decreases and becomes more patchy, and so does the number of HII regions for $\ell > 40^\circ$. This again is consistent with the fact that the galactic ridge recombination lines are seen only upto $\ell \approx 40^\circ$.

All the observational evidence is therefore consistent with the hypothesis that the galactic ridge recombination lines arise in low density extended envelopes of conventional HII regions. It is no longer necessary to invoke any distributed component of the interstellar medium to account for these lines.

It should be mentioned that an origin for the ridge recombination lines in outer parts of HII regions is not a new idea. Based on their H166α observations of the extended gas associated with the HII region W3 ($l=138^\circ$), Hart and Pedlar (1976a) have in fact made such a suggestion. However this HII region is well away from the longitude range where the galactic ridge lines are observed, and therefore, the above authors concluded by saying that their observation do not in any way prove their suggestion but that it is a possible explanation.

Lockman (1980) noted the correlation between his observed 166α spectra and the composite 1104 spectra formed by adding the H110α profiles from the survey of Downes et al (1980). He used this correlation to conclude that most of the 166α emission comes from extended outer parts of normal HII regions whose dense cores are prominent in the radio continuum This is identical to the conclusion we have drawn from the analysis of the 272α lines.

However, Lockman distinguished the 166α emission near $\ell=36^\circ$ as coming from a more broadly distributed medium that extends over a few hundred parsecs and has a density of ~ 1 cm^{-3} and a temperature of a few thousand degress. His estimated parameters for this region are not unique, and in his analysis higher densities and smaller path lengths would be allowed for this gas. An increase in density to a mere 3 cm^{-3} will make this gas similar to the ones responsible for the observed 272α lines in the direction of SNRs, blank areas and HII regions. In other words, this gas would have properties similar to the regions responsible for galactic ridge recombination lines (namely the outer envelopes of conventional HII regions).

The parameters derived by Shaver (1976) for the regions responsible for the ridge lines (density 5-10 cm^{-3}, path length 20-150 pc and temperature of 5000K) are similar to the ones obtained by us in the previous chapter. He however concluded that these are weak HII regions. Our conclusion differs in only one way from that of Shaver, namely that we attribute this gas to extended outer envelopes of normal HII regions. To explain the smooth distribution of the 166α line emission (and also of 272α, except that we do not have that many observations) Shaver's picture would require a large number of such weak HII regions.

If these are distinct from conventional HII regions which are prominent in the radio continuum, then it would be difficult to explain the excellent agreement in the velocities of H110α, H166α and H272α lines in the direction of normal HII regions.

Although as shown earlier, the low density envelopes of conventional HII regions will intersect practically every line of sight having $\ell \leq 40^{\circ}$ there can very well be variations 'in density and emission measure from one line of sight to another. HII regions are not ideal, homogeneous uniform density objects. There would be a radial gradient as well as fluctuations in the density both in the core and in the outer envelope. As a result, one can expect variations in the line intensity even in adjacent directions as observed by Jackson and Kerr (1975) using a beam of 6 arcminutes.

In conclusion we have been able to show that most and probably all of the galactic ridge recombination lines arise in extended outer envelopes of conventional HII regions. Although others (Hart and Pedlar 1976, Lockman 1979) have previously suggested a similar explanation they were not able to separate the ridge emission from that of the normal HII regions themselves, because of the higher frequency lines (166α) used for the analysis. The 272α observations of the present study, on the other hand has the unique advantage that they are almost completely insensitive to emission from conventional HII regions because of pressure broadening, optical depth and beam dilution. These observations have sampled practically only that gas which is responsible for the galactic ridge recombination lines. Using the strong dependence of the intensity of the 272α lines on the density of the emitting gas, we have been able to deduce the properties of the regions which produce the galactic ridge recombination lines.

CHAPTER 8

SUMMARY AND CONCLUSIONS

In this thesis we have presented an observational study of recombination line emission from the galactic plane at 325 MHz. The observations were made using the Ooty Radio Telescope which has an angular resolution of 2° in the east-west direction and $\sim 6'$ in the north-south. A total of 53 directions, most of them in the first quadrant of the Galaxy ($\ell = 0^{\circ}$ to 60°) were observed. The observations include a few well known sources in the anticentre direction like the Orion and the Rosette nebulae. The 53 directions observed consisted of 34 corresponding to well known HII regions, 12 to SNRs and 6 to 'blank' areas in the galactic plane where the continuum emission is a minimum and free of discrete sources over the beam of the telescope. In addition the direction of the galactic centre was also observed.

This is the first major survey of recombination line emission from the galactic plane at a low frequency. Earlier surveys have all been made at frequencies higher than 1 GHz. These observtions made over a period of 3 years also constitute the first major spectral line study using the Ooty Radio Telescope.

The observational program involved building, installing and testing of several new items of equipment and associated computer software development to make the Ooty telescope suitable for spectral line observations. A 128 channel one-bit autocorrelator and a local oscillator system built for this purpose have been described in this thesis. Considerable time was spent in evolving a suitable observing procedure and data reduction methods in order to get good baselines and calibrations for the spectra, and also to take precautions against interference which generally plagues low frequency observations.

Of the 53 directions observed, the H272α line was detected towards 47 of the directions and possible carbon lines (272α) in 12 directions. ,Hydrogen recombination lines were detected towards all the directions having galactic longitude $\ell < 40^\circ$. The line intensities are typically 0.1% of the total continuum intensity (which includes the galactic non-thermal background), and are similar for all the lines detected irrespective of whether the direction corresponded to that of an HII region, an SNR or a blank region. The lines are generally weak, and they have a signal to noise ratio between 5 and 10. It required from 10 to 30 hours of integration for detecting each of these lines. The typical width of the lines (FWHM) is 20-50 Km/s. However, the lines are much wider (60-80 Km/s), or have more than one component, for many sources with longitude $\ell > 20^\circ$. The strongest line detected is towards the galactic centre. The profile clearly shows 3 components; one centred at 0 Km/s, one around -50 Km/s and the other at a positive velocity.

We first looked at the broad characteristics of the data. The observed line intensities were found to correlate well with the total continuum intensity (correlation coefficient 0.78) which includes the galactic background. As the total continuum intensity at this frequency is dominated by the non-thermal galactic background, this correlation clearly implies that most of the observed lines arise due to stimulated emission by background radiation. Such a correlation is also observed at higher frequencies (e.g. Mathews et al 1973, Jackson and Kerr 1975). But at these frequencies the continuum is mostly thermal and would be emitted from the same regions which produce the lines. Therefore, a correlation would be expected even in the absence of stimulated emission. At low frequencies however, any such observed correlation can only be due to stimulated emission due to the dominance of the galactic background.

We then compared the observed velocities of the 272α lines with those of higher frequency lines (mostly H110α) wherever available. There is generally a very good agreement in most of the cases 080%) indicating that the regions responsble for the two sets of lines are physically associated. A comparison was then made of the longitude -velocity diagram of the observed 272α lines with those of higher frequency recombination lines (like H166α and H110α), 21 cm neutral hydrogen lines and 2.6 mm wavelength CO lines. The comparison indicated that the distribution in the galactic disk of the regions responsible for the 272α lines is similar to those of HII regions observed in the H110α and H166α lines and molecular clouds seen in the CO lines.

It was necessary to make use of other observations pertaining to the same gas in order to derive the physical properties like temperature density and sizes of the regions responsible for the observed 272α lines. This is because there are more parameters that characterize a line emitting region in a given direction than the number of quantities that are obtained from a line measurement in that direction (line intensity and width), The observed widths of the 272α lines implied upper limit for the electron density of ~60 cm^{-3} for the line emitting regions from considerations of pressure broadening and optical depth.

The present 2724 observations towards blank regions can be considered as similar to the centimeter wavelength observtions of galpctic ridge recombination lines. The latter are also made towards regions in the galactic plane where the continuum emission is a minimum (e.g. Gottesman and Gordon 1970, Mathews et al 1973, Jackson and Kerr 1975). When recombination lines are observed towards such a region at more than one frequency, it is reasonable to attribute the emission to the same gas. At the position of the 6 blank regions observed here, 166α lines have been observed by Lockman (1976).

Because of the dominance of the stimulated emission at the 272α line frequency and that of spontaneous emissibn at the 166α frequency, the dependence of the intensity of the two lines on the density of the .line emitting region is very different. The intensity of the lower frequency line is nearly proportional to the density of the gas, and that of the higher frequency to the emission measure (or square of the electron density for fixed path length). Therefore, if we attribute the lines observed at the two frequencies to the same gas, then the density gets determined almost uniquely irrespective of the temperature and emission measure. We have made use of this property and determined the density of the ionized regions responsible for the lines observed towards blank regions. The deduced densities are in the range 1 - 6 cm^{-3}. With the densities determined, an upper limit to the temperature of these regions of 5000-8000K is implied by the intensity of the 5 GHz continuum observed at these positions. Similar upper limits are implied by consideration of the average interstellar electron density deduced from pulsar dispersion measures (Vivekanand and Narayan 1982). We have ruled out temperatures much lower than a few thousand degrees using geometrical considerations. Lower temperatures would imply very small path length ($\sim$ few pc) through the gas. The extent of the gas perpendicular to the line of sight as deduced from 166α observations (Lockman 1976, Hart and Pedlar 1976) is $\sim$100 pc. The small path lengths implied by low temperatures would therefore require the line emitting regions to have peculiar geometries. They should either be in the form of thin extensive sheets (perpendicular to the line of sight) or small cloudlets distributed along the line of sight with appropriate filling factors. Both these geometries would be inconsistent with the observed line profiles. We have therefore concluded that the gas responsible for the observed 272α lines has densities in the range of 1 - 10 cm^{-3}, temperatures greater than a few thousand degrees but less than 8000K, and emission measures in the range 500-3000 pc cm^{-6}. The corresponding path lengths through the gas are 50-150 pc along the line of sight.

Similar considerations were applied to the observations towards SNRs. Higher frequency recombination line measurements are available towards some of the observed SNRs (e.g. Cesarsky and Cesarsky 1973, Bignel 1973, Downes and Wilson 1974). The parameters deduced for the line emitting regions towards SNRs are very similar to those towards blank regions. The observations towards SNRs can also be considered similar to the galactic ridge line observations since the SNRs themselves are not expected to emit any recombination lines but only add to the continuum background.

The interpretation of the lines observed towards HII regions posed a problem For most of these HII regions their properties like size temperature, density and emission measure are known from high frequency continuum and line observations (e. g. Shaver and Goss 1970b, Downes et al 1980). The upper limits to the density of the gas responsible for the 272α lines implied by their widths from pressure broadening considerations are much less (by a factor of 5-10) than the known densities of the HII regions except in one or two cases. Further, most of the HII regions are optically thick at this frequency. In addition, the beam dilution factor for them is 10^{-2}-10^{-3} due to their few arcminutes size and the 2° x 6' beam used for the observations. For these reasons the observed 272α lines simply can not be produced in these HII regions themselves. The lines must originate in some other lower density gas, along the line of sight. In essence, the directions of HII regions are almost similar to those of blank regions as far as the present observations are concerned. In all these directions there are no prominent continuum sources which can produce the observed recombination lines. In other words, all of the present observations in the first quadrant of the galaxy can be considered as similar to those at centimeter wavelengths which detected the galactic ridge recombination lines. The latter were usually made towards regions of continuum minimum to make sure that HII regions do not contribute to the observed lines. On the other hand, the low frequency and the large beam width used for the present observations ensures that the HII regions do not produce any detectable line emission irrespective of the direction of observation.

A clue to the location of the low density gas in the direction of HII regions is given by the observed velocity of the 272α lines. In a surprisingly large number of cases (>70%) the central velocity of the 272α line agrees to within ±10 Km/s of the velocity of the HII region observed in the H110α line. Within the observational errors in their determinations (they are ∼2-5 Km/s for both), the velocities match with each other. In any case, there is always a substantial emission of the 272α line at the velocity of the HII region in more than 90% of the cases. This clearly implies that the low density gas responsible for the 272α emission is associated with the dense HII region towards which the lines are observed. The most reasonable picture for this association is that the low density gas forms the outer envelope of the dense HII region. A kind of a core-halo picture thus emerges for the HII regions. There is both theoretical justification and observational evidence for such a picture (Zukerman 1973, Hart and Pedlar 1976a).

In the case of the HII regions it was not possible to deduce the density of the outer envelopes from the observed 2724 lines, using the same technique as for the blank regions and SNRs, namely to combine the 272α measurement with another at a high frequency. This is because the problem of pressure broadening, beam dilution and optical depth effects do not exist for the high frequency lines. Therefore, the conventional HII regions produce easily detectable recombination lines at higher frequencies. Most of the line intensity observed at high frequencies will in fact come from the HII region itself. It will be virtually impossible to separate out the contribution from the low density envelope. We used a somewhat different method to deduce the densities, sizes and temperatures of these regions.

We argued that the temperature of the low density outer envelopes cannot be very different from that of the HII region itself. This is because the temperature of an ionized region depends almost entirely on the abundance of heavy ions, and is only very weakly dependent on the density of the gas and the effective temperature of the exciting star. The abundances of these ions are unlikely to be very different in the central and outer parts of an HII region. We therefore assumed that the temperature of the outer envelopes which produce the 272α lines are the same as that of the HII regions. The temperatures for the HII regions were taken from high frequency determinations (e. g. Downes et al 1980).

With the temperature of the region fixed, the observed intensity of the H272α line was used to establish a relation between the electron density of the gas and its emission measure. To determine both these quantities we imposed what we considered a reasonable constraint on the geometry of the envelope, namely that the extent of the envelope along the line of sight be comparable to its dimension perpendicular to it. Given a beam dilution factor for the outer envelope, this constraint will lead to a determination of both emission measure and density of the gas. We estimated the most probable beam dilution factor to be 0.6 based on the latitude extent of the 166α line emission observed by Lockman (1976) and Hart and Pedlar (1976). In any case, beam dilution factors of <0.2 were not allowed as the densities determined would then be higher than the upper limits implied by the observed line widths.

The densities and emission measures of the outer envelopes determined using the above method for all the HII regions are in the range of 1-10 cm^{-3} and 1000-5000 pc cm^{-6} respectively. The corresponding path lengths through the outer envelopes are in the range 50-300 pc.

Usng a model of galactic rotation (Schmidt 1965), we obtained the distribution of the low density gas responsible for the observed 272α lines as a function of distance from the galactic centre. The distribution shows a peak between 4 kpc and 8 kpc and is very similar to that of HII regions seen in the H110α lines (Downes et al 1980). This distribution also agrees with that obtained by Lockman (1976) using his 166α observations. The molecular clouds observed in their CO emission also show a similar peaking between 4 kpc and 8 kpc from the galactic centre. On the other hand, neutral hydrogen seen in 21 cm emission has a very different distribution. The HI distribution is nearly uniform and extends out to >14 kpc from the galactic centre.

We finally considered the origin of the galactic ridge recombination lines. As mentioned earlier the present observation has practically detected only that gas which is responsible for the ridge lines. This can be seen from the similarity of the properties of the gas derived from observations towards blank regions, SNRs and HII regions. Further we identified the low density gas in the direction of HII regions with their outer envelopes based on the excellent agreement between the velocities observed at low and high frequencies. The ahove evidence led to the conclusion that most and probably all of the galactic ridge recombination lines arise in the extended outer low density envelopes.

This conclusion is consistent with the fact that the distribution of the low density gas seen in the present 272α survey is practically identical to that of conventional HII regions in the inner part of the galaxy. Further, in the longitude range $l \leq 40^\circ$ these HII regions are so large in number that given the kind of extended envelopes whose properties are derived from the present observations, their outer regions will practicaly intersect every line of sight within this longitude range thereby giving rise to the observed galactic ridge recombination lines.

It was possible to arrive at this conclusion because the present 272α observations have the unique advantage that they are insensitive to emission from conventional HII regions. Although others have suggested a similar explanation for the galactic ridge lines (Hart and Pedlar 1976a, Lockman 1980) they were not able to separate the contribution from normal HII regions becuse of the higher frequencies used for their observations. The 272α observations on the other hand have seen practically only that gas which is responsible for the galactic ridge recombination lines.

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