The Universe at Low Radio Frequencies
IAU Symposium, Vol. 199, 2002
A. Pramesh Rao, G. Swarup and Gopal-Krishna, eds.

A Study of Low density Ionized Gas in the Galactic Plane

D. Anish Roshi
National Centre for Radio Astrophysics, TIFR, Post Bag 3, Ganeshkind, Pune 411007, India

K. R. Anantharamaiah
Raman Research Institute, Bangalore 560080, India

Abstract. A complete survey of radio recombination lines (RRLs) near 327 MHz from the galactic plane (l = 330°– 0°–89°, b = 0°) was carried out using a section of the Ooty Radio Telescope (ORT) with an angular resolution of 2°× 2°. A subset of regions in the same area was observed using the whole telescope which has a beam of 2°× 6′. Hydrogen RRLs were detected in most of the positions that were observed. The lv diagram and radial distribution computed from the observed spectra and their comparison with other species in the galactic plane indicate that the low density gas detected in the survey is distributed similar to the star forming regions. For an assumed temperature of 7000 K, we estimate that the densities and sizes of the regions are in the range 1 – 10 cm^{-3} and 20 – 200 pc respectively. Our data suggests that the low density ionized gas is in the form of outer envelopes of normal HII regions.

1. Introduction

Radio recombination lines are an useful tool for studying the properties of different types of ionized gas in the Galaxy. The galactic plane contains several forms of ionized gas. Along with the distributed ionized gases, such as the warm ionized medium (WIM) and the hot ionized medium (HIM), there are a variety of H II regions over a wide range of densities ($n_e \sim 1 - 1000$ cm^{-3}) and a relatively narrow range of temperatures ($T_e \sim$ 3000 - 10000 K). The sizes of these regions range from a few parsecs to few tens of parsecs. In addition, there also appears to be a low density extended ionized component in the inner Galaxy. This component has been referred to as "extended low density" (ELD) ionized gas by Mezger (1978), as H II -envelopes by Anantharamaiah (1986) and as "extended low density warm ionized medium" (ELDWIM) by Petuchowski & Bennett (1993), Heiles (1994) and Heiles, Reach & Koo (1996). Observationally, this low density ionized gas in the inner Galaxy was identified through the detection of low frequency (< 2 GHz) RRLs at several positions along the galactic plane. (Gottesman & Gordon 1970) From the theory of RRLs, it can be shown that the low frequency lines originate from low density ionized gas and thus form an ideal tool to study the extended low density gas. This paper concerns

https://doi.org/10.1017/S0074180900169244 Published online by Cambridge University Press

new extensive observations of this low density ionized component in RRLs at frequencies near 327 MHz using the ORT.

2. Observations

The key to understand the extended low density ionized gas in the inner Galaxy is to determine its physical properties such as density, temperature and sizes of the regions and to determine the distribution of the gas in the galactic plane. With these objectives in mind, we made a survey of RRLs near 327 MHz in the galactic plane using the ORT. Two sets of H270α, H271α, H272α and H273α RRL transitions were observed simultaneously using a new multi-line spectrometer. The eight spectra are averaged to improve the signal to noise ratio and thus reducing the observing time by a factor of eight.

Observations were made in the two longitude ranges; $l = 350^o$ to 0^o to 80^o, referred to as the inner Galaxy, and $l = 172°$ to $252°$, the outer Galaxy. The inner Galaxy was observed with two different angular resolutions – (a) 2° × 2° (low resolution mode) and (b) 2° × 6′(high resolution mode). The lower resolution (2° × 2°) is obtained by using only a single 'module' of the ORT, which effectively is a telescope of size 24 m × 30 m, and the higher resolution (2° × 6′) is obtained by using the full telescope. In the low resolution mode, we made an unbiased contiguous sampling of the galactic plane in the inner Galaxy and also observed 14 positions ($b = 0°$) in the outer Galaxy. To study the latitude extent of the line emission, we observed over ± 4°along galactic latitude at two specific longitudes ($l = 0°$& 13°.9). In the high resolution mode, we sampled a selected set of 2° and 6° wide fields in the inner Galaxy. About 300 spectra were obtained in all these observations, which cover a total sky area of $\sim$ 345 square degree.

3. Results from the Low Resolution Survey

In the low resolution survey, hydrogen RRLs were detected at almost all positions in the inner Galaxy. In the outer Galaxy, lines were marginally detected towards only three positions. The observations as a function of the galactic latitude detected lines up to $b \sim \pm 3°$.

3.1. *lv* diagram and Radial Distribution

The *lv* diagram and the radial distribution constructed from the RRL emission near 327 MHz shows good similarity with that of RRL emission near 1.4 GHz, "intense" ^{12}CO emission at 3 mm and to some extent with the RRLs observed near 3 cm from normal H II region (see Fig. 1). These distributions are distinctly different from that of Hα emission and H I emission from the Galactic disk. The difference in the distribution between RRL and Hα is mainly due to obscuration by dust of the Hα emission and difference in sensitivity of recombination lines in optical and radio bands. Based on the similarity in the distribution of RRL emission at 327 MHz, ^{12}CO emission and RRL emission from normal H II regions, we conclude that the diffuse RRL emission in the galactic disk is associated with star forming regions. We also conclude that most of the line emission near 1.4

https://doi.org/10.1017/S0074180900169244 Published online by Cambridge University Press

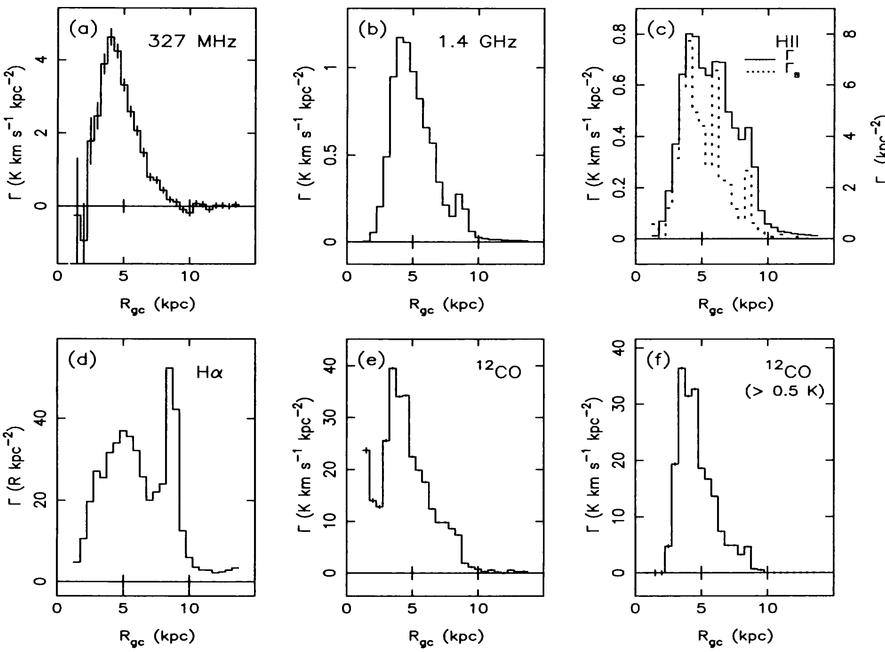

Figure 1. Plots of the radial distribution (average emission Γ vs galactocentric radius R_{gc}) of different components of the ISM. They are obtained from (a) RRL emission near 327 MHz, (b) RRL emission near 1.4 GHz, (c) RRL emission from H II regions near 3 cm (solid line), (d) Hα emission, (e) ^{12}CO emission and (f) ^{12}CO spectral components of intensity higher than 0.5 K. The surface density (Γ_s) of H II regions as a function of galactocentric radius is plotted as dotted line in (c).

GHz originates from the same ionized gas which is responsible for the RRL emission near 327 MHz.

3.2. Physical Properties

Constraints on the physical properties of the line emitting region are derived by combining the existing RRL observations near 1.4 GHz with the present 327 MHz data. The measured line strengths at 1.4 GHz and 327 MHz place a good constraint on the density of the ionized gas. The derived densities are in the range 1 – 10 cm^{-3} . Using the measured continuum near 10 GHz and 2.7 GHz, the upper limit on the RRL intensity near 75 MHz and the dispersion measure ($\int n_e dl$) obtained from the electron density model by Taylor & Cordes (1993), we obtain upper limits on the temperature and the physical size of the ionized region in different directions. The upper limits obtained for the temperature are typically 10000 K and that for the pathlengths are typically 600 pc. By assuming a temperature of 7000 K for the ionized cloud, we estimated the sizes of the line emitting region to be in the the range 20 – 200 pc.

4. Results from the Higher Resolution Observations

The higher resolution ($2^\circ \times 6'$) observations were used to study the clumpiness of the low density ionized gas in the galactic plane. The fields that were observed using the full ORT are positions where lines were detected in the low resolution survey made using a single module of the ORT. In the higher resolution observations, the hydrogen lines were detected at almost all positions within all the five selected fields with $l < 35^\circ$. A detailed study of the data from one of the fields, G45.5+0.0, shows that the line emission extends to regions beyond the $2^\circ \times 6'$ beam area. Averaging subsets of spectra spanning different angular regions within the field G45.5+0.0 resulted in lines with different parameters indicating that the line emitting region is quite clumpy. We estimate that the sizes of the clumps can be as large as one degree or more. There exists some evidence for the association of these clumps with known H II regions within this field.

5. Origin of the Low density Ionized Gas

The pathlengths obtained for the ionized gas from the RRL observations are in the range 20 – 200 pc implying that the filling factor of this medium is only 2% or less. This low filling factor clearly indicates that the low density gas is not a pervasive medium. Analysis of the RRL emission in the disk shows that the global distribution of the ionized gas responsible for the line emission is similar to that of star forming regions. This similarity suggests that the line emitting zones may be associated with normal H II regions. H II regions with large low density outer components are expected from models of star formation (Zuckerman 1973). Recent study of the luminosity function of OB associations in the Galaxy also indicates that radio H II regions have envelopes that absorb $\sim$ 2/3 of the ionizing photons from the H II regions (McKee & Williams 1997). Thus, in our opinion, the low frequency RRLs originate from extended low density components associated with normal H II regions. The low density gas does not form a pervasive medium as might be suggested by the term Extended Low density Warm Ionized Medium (ELDWIM) which has been used in the literature to describe this component (Mezger 1978, Petuchowski & Bennett 1993, Heiles 1994, Heiles, Reach & Koo 1996).

References

Anantharamaiah, K. R. 1986, JAA, 7, 131

Gottesman, S. T., Gordon, M. A. 1970, ApJ, 162, L93

Heiles, C. 1994, ApJ, 436, 720

Heiles, C., Reach, W. T., Koo, B.-C. 1996, ApJ, 466, 191

Mezger, P. G. 1978, A&A, 70, 565

Petuchowski, S. J., Bennett, C. L. 1993, ApJ, 405, 591

Taylor, J. H., Cordes, J., M. 1993, ApJ, 411, 674

Zuckerman, B. 1973, ApJ, 183, 863