From Stars to Galaxies: Building the Pieces to Build Up the Universe. ASP Conf. Ser. Vol. 374, Ed. A. Vallenari, R. Tantalo, L. Portinari, A. Moretti, 169-174 (2007)

The Abundance Gradient in the Galactic H II Regions

Robert T. Rood[1], Cintia Quireza[2,1,3], T. M. Bania[4], Dana S. Balser[5] & Walter J. Maciel[3]

Abstract. We derive the electron temperature gradient in the Galactic disk using a sample of H II regions that spans Galactocentric distances 0–17 kpc. The electron temperature was calculated using high precision radio recombination line and continuum observations for more than 100 H II regions. The large number of nebulae widely distributed over the Galactic disk together with the uniformity of our data provide a secure estimate of the present electron temperature gradient in the Milky Way. Because metals are the main coolants in the photoionized gas, the electron temperature along the Galactic disk should be directly related to the distribution of heavy elements in the Milky Way. Our derived abundance gradient is considerably flatter than the oft cited value of Shaver et al. (1983) (S83). There are no significant variations in the value of the gradient as a function of Galactocentric radius or azimuth. The scatter we find in the H II region electron temperatures at a given Galactocentric radius is not due to observational error, but rather to intrinsic fluctuations in these temperatures which are almost certainly due to fluctuations in the nebular heavy element abundances.

1. INTRODUCTION

Churchwell & Walmsley (1975) pioneered H II region radio recombination line (RRL) studies of the relationship between nebular electron temperatures, T_e, and Galactocentric distance, $R_{\rm gal}$, (Churchwell et al. 1978; Wink et al. 1983; S83; and others). Because RRLs are not obscured by interstellar dust, relatively faint H II regions at extremely large distances from the Sun could be detected. They found that there was a Galactic temperature gradient wherein T_e is low in the Galactic Center and increases with $R_{\rm gal}$. The value of T_e is set by the cooling rate which depends primarily on the abundance of heavy elements or "metals." In the current context oxygen (O) is normally used as a measure of overall metallicity, and T_e decreases as O increases.

[1]Astronomy Department, 400325, University of Virginia, Charlottesville VA 22904, USA.

[2]Observatório Nacional, Rua General José Cristino 77, 20921-400, Rio de Janeiro, RJ, Brazil.

[3]Instituto de Astronomia, Geofísica e Ciências Atmosféricas (IAG), Universidade de São Paulo, Rua do Matão 1226, 05508-900, São Paulo, SP, Brazil.

[4]Institute for Astrophysical Research, Department of Astronomy, Boston University, 725 Commonwealth Avenue, Boston MA 02215, USA.

[5]National Radio Astronomy Observatory, P.O. Box 2, Green Bank WV 24944, USA.

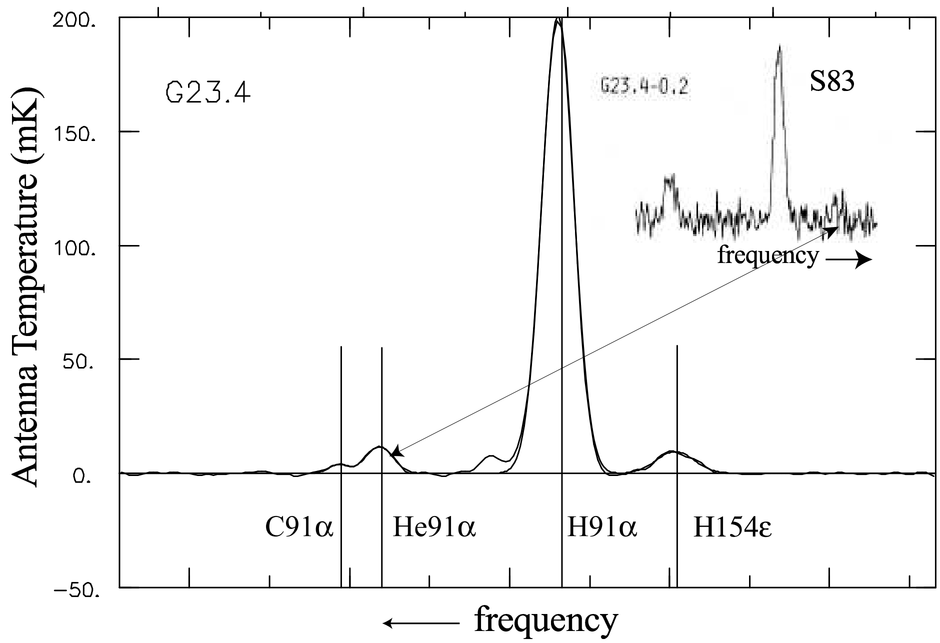

Figure 1. The 91α spectrum for the H II region G23.4, which is typical of the results from the ^{3}He survey. The spectrum of the same H II region from S83 is shown in the upper right. The x-axis is flipped. The three lines are H137β, H109α, & He109α

.

Here we present a brief description of our recent work on the T_e gradient measured using RRLs. The details can be found in Quireza et al. (2006b). The underlying data can be found in Quireza at al. (2006a).

2. BACKGROUND

A determination of T_e of an H II region requires a measurement of the width and intensity of a RRL along with a measurement of the radio continuum intensity. Our results are derived from observations of the H91α and H92α RRLs with frequencies of roughly 8.6 GHz (3.5 cm) and continuum observations which were interleaved with the line measurements. The spectroscopy was a byproduct of two large projects: *The 3-Helium Project* (Rood et al. 1984; Bania et al. 1987, 1997; Balser et al. 1994) and *The Carbon Recombination Line Survey* (Quireza et al. 2006a). Both projects were conducted at the Green Bank 140 Foot Radio Telescope of the NRAO.[1] The observations were made over a period of more than a decade and were all carefully cross calibrated. For various reasons we observed α transitions as we observed our weak target lines. In the first project we were searching for the hyperfine line of $^3He^+$ with an anticipated intensity of ~ 1 mK.

[1]The National Radio Astronomy Observatory (NRAO) is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

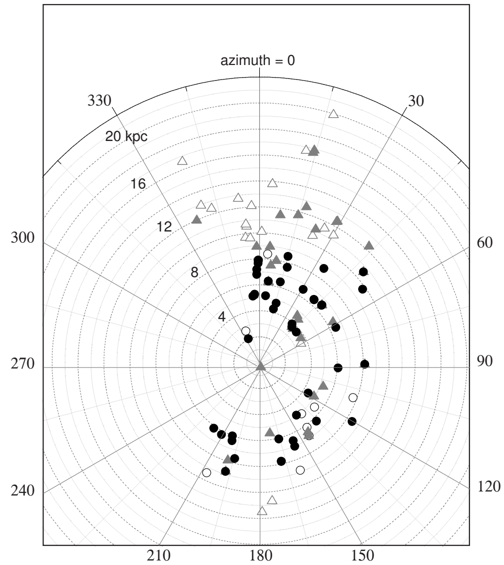

Figure 2. Distribution of the H II region sample projected onto the Galactic plane plotted as a function of Galactocentric radius and azimuth. Different symbols identify the ^{3}He (triangles) and C II survey (circles) nebulae. Filled symbols denote our highest quality data; open symbols flag our poorer quality data.

The α transitions are typically 100's of times brighter. In the second project the C II RRL typically a factor of 30–100 times weaker than the associated α transition. Because our target lines were so weak, we were also forced to develop techniques to minimize the effect of systematic errors, the most problematic of these being removing spectral baselines.

Figure 1 is typical of our α transition spectra in either survey. The H91α line is essentially noiseless and coincident with the best fit gaussian. The spectrum for the same H II region from S83 is shown in the upper right. With our long integration time and over a decade of improvements in receiver technology it is not surprising that our result is much better. The long arrow points out the two He lines: ours is almost exactly what would be expected from scaling the H line; in S83 the He line is recognizable but not much more than that.

Our sample has 106 sources: 47 nebulae from the ^{3}He survey and 66 from the C II survey. (There are 7 objects in common.) The distribution of the sources in the Milky Way is shown in Figure 2. The open symbols show sources with poorer quality data which could not be included in the present analysis. In many cases the problem arises from poor continuum data either because the H II region was in a crowded part of the Galaxy where it was difficult to establish a baseline continuum, or particularly for outer Galaxy H II regions, the continuum intensity was too low to measure accurately with the cross scans we used. Unfortunately many of the excluded sources are in very interesting parts of the Galaxy.[2] Our

[2]It would be relatively easy to obtain improved continuum observations for many of these sources, and we intend to do so.

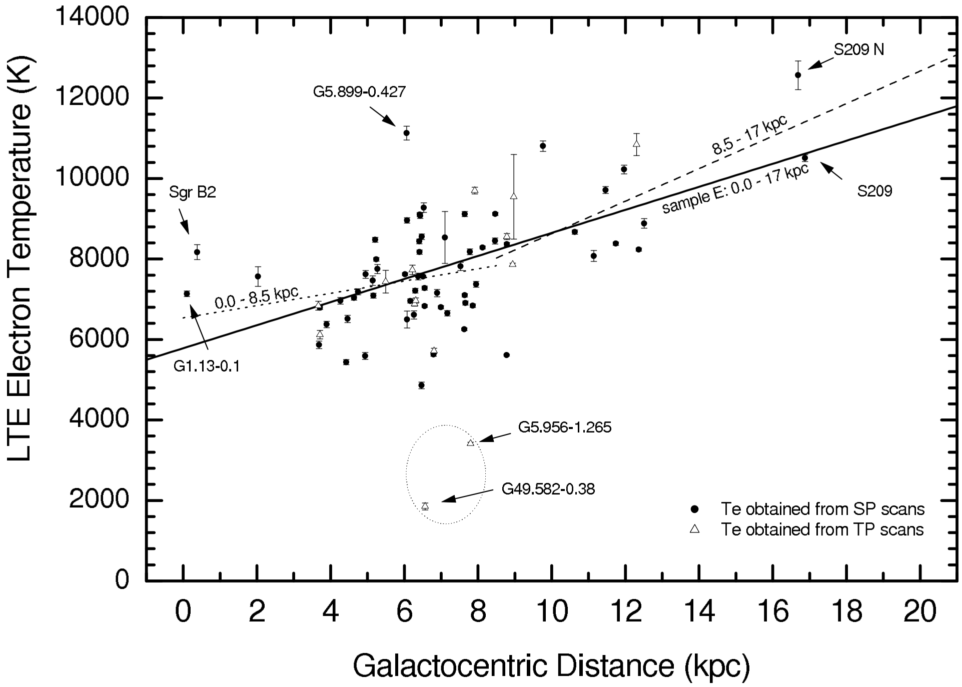

Figure 3. Nebular LTE electron temperature plotted as a function of the Galactocentric distance for the best data. Least squares linear fits to the gradient for the entire sample and, separately, for nebulae located inside and outside the solar orbit are shown.

final sample described here was 76 or 73 depending on whether Galactic center sources are included or not.

3. RESULTS

Our resulting T_e values are shown as a function of $R_{\rm gal}$ in Figure 3. *Error bars are shown for all points,* even though there are barely visible in most cases. There is a suggestion that the slope is smaller inside the Solar circle, but the two segment fit is not statistically better than the single fit. It is most appropriate to exclude the points near the Galactic center in comparing to previous results. We find $dT_e/dR = 340 \pm 45\,{\rm K\,kpc^{-1}}$. This is very close to the value found by Wink et al. (1983) and, perhaps surprisingly, that of Aflerbach, et al. (1996) who observed ultracompact H II regions.

S83 is one of the most commonly cited papers in chemical evolution studies (623 total citations with 27 in 2006). It is the one result which seems inconsistent with ours. Their slope is significantly steeper (27%) than ours.

The S83 sample of 67 H II regions was made up of 44 H II regions with H109α observations and 23 with H76α observations. Our T_e values are completely consistent with the S83 values obtained using the H76α data. The discordance between our work and S83 arises mostly from the low T_e points located between

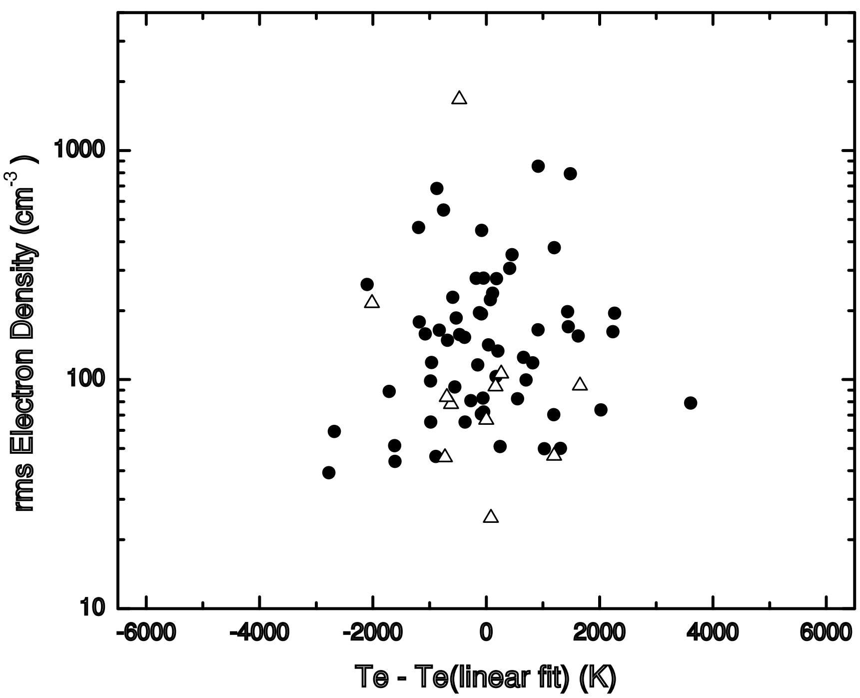

Figure 4. The rms electron density as a function of the difference between the observed T_e and the best linear fit of T_e versus $R_{\rm gal}$.

$R_{\rm gal} = 4$–6 kpc with T_e based on the H109α lines. The various factors that could steepen the S83 gradient are discussed in Quireza et al. (2006b).

The scatter in the points in Figure 3 is even more striking than the slope. Almost certainly the systematic errors are much larger than the statistical errors indicated by the error bars. We suspect that the largest systematic errors are due to the continuum measurements and errors in $R_{\rm gal}$. We can make a reasonable estimate of the first, and it seems a small contributor to the scatter. We suspect the same is true of the distances.

Various physical phenomena could also affect T_e. For example, higher electron density could dampen cooling processes and raise T_e. If this were an important effect we would expect to find higher T_e in higher density H II regions. Figure 4 shows that this is not the case. We have searched for many similar correlations and found none.

We conclude that the scatter in T_e at a given $R_{\rm gal}$ is due to a scatter in heavy element abundance. Our observed T_e dispersion is $\sim 2200\,$K (FWHM) would correspond to an [O/H] abundance dispersion of ~ 0.3 dex (FWHM).

Our resulting abundance gradient is shown in Figure 5. The slope is $-0.043 \pm 0.007\,{\rm dex\,kpc^{-1}}$.

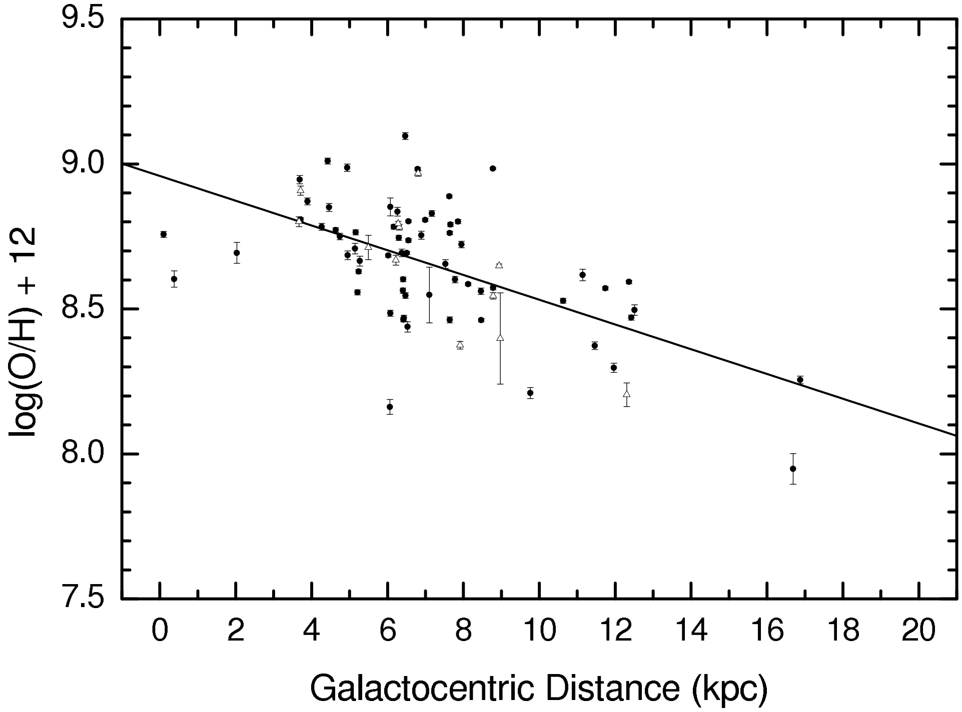

Figure 5. The Galactic O/H abundance gradient derived from our nebular electron temperatures using the relation between O/H and T_e of S83. The solid line is the least squares fit.

Acknowledgments. We thank the staff of NRAO Green Bank for their help, support and friendship. The ^{3}He research has been sporadically supported by the National Science Foundation. The most recent grants were AST 00-98047 to TMB and AST-0098449 to RTR.

References

Afflerbach, A., Churchwell, E., Acord, J.M., Hofner, P., Kurtz, S., & De Pree, C. G. 1996, ApJS, 106, 423

Balser, D. S., Bania, T. M., Brockway, C. J., Rood, R. T., & Wilson, T. L. 1994, ApJ, 430, 667

Bania, T. M., Rood, R. T., & Wilson, T. L. 1987, ApJ, 323, 30

Churchwell, E., & Walmsley, C. M. 1975, A&A, 38, 451

Churchwell, E., Smith, L. F., Mathis, J., Mezger, P. G., & Huchtmeier, W. 1978, A&A, 70, 719

Quireza, C. Q., Rood, R. T., Balser, D. S., & Bania, T. M. 2006a, ApJS, 165, 338

Quireza, C. Q., Rood, R. T., Balser, D. S., Bania, T. M., & Maciel, W. J. 2006b, ApJ, 653, 1226

Rood, R. T., Bania, T. M., & Wilson, T. L. 1984, ApJ, 280, 629

Shaver, P. A., McGee, R. X., Newton, L. M., Danks, A. C., & Pottasch, S. R. 1983, MNRAS, 204, 53 (S83)

Wink, J. E., Wilson, T. L., & Bieging, J.H. 1983, A&A, 127, 211