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A NEW DETERMINATION OF THE GALACTIC ELECTRON TEMPERATURE GRADIENT FOR EXTENDED AND LOW DENSITY IONIZED GAS

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RESUMEN

Utilizando valores de temperaturas electrónicas obtenidas a partir de observaciones de líneas de recombinación H166α del continuo en 1.4 GHz de 19 regiones H II, junto con temperaturas obtenidas por Pedlar (1980) de observaciones de la misma línea de recombinación en regiones H II de baja densidad (con un haz de antena similar) y un valor de temperatura electrónica dado por Pedlar *et al.* (1978), se obtiene una nueva determinación de un gradiente de la temperatura electrónica con el radio galactocéntrico para el gas ionizado de baja densidad.

ABSTRACT

By using electron temperature values derived from H166α recombination line and 1.4 GHz continuum observations of 19 H II regions, together with those given by Pedlar (1980) from H166α observations of low-density H II regions (with similar antenna beam) and a value of electron temperature given by Pedlar *et al.* (1978), a new determination of a galactic electron temperature gradient with the galactocentric distance is obtained for the low-density ionized gas.

Key words: **NEBULAE-H II REGIONS – GALAXY-STRUCTURE – RADIO LINES-RECOMBINATION**

I. INTRODUCTION

The presence of a galactic temperature gradient vith the galactocentric distance of H II regions s known since several years ago, from surveys of adio recombination lines carried out at different requencies: H109α (Churchwell *et al.* 1978), I110α (Downes *et al.* 1980), H66α (Wilson, Pauls nd Ziurys 1979), H86α (Lichten, Rodríguez and haisson 1979), H76α (Mc Gee and Newton 1981; Vink, Wilson and Bieging 1983), H125α (Garay nd Rodríguez 1983), H166α (Azcárate, Cersosimo nd Colomb 1985), H110α (Caswell and Haynes 987) and some observations of β lines (Churchwell *t al.* 1978; Lichten *et al.* 1979). This gradient eems to be present also for low-density ionized gas, ccording to H125α (Garay and Rodríguez 1983) nd previous H166α observations (Azcárate *et al.* 985).

The main purpose of this paper is to obtain a new determination of the value of the galactic electron temperature gradient for the low density gas, from H166α line and 1.4 GHz continuum observations. To this end, we use electron temperature results from extensive H166α line observations (several points for each region, about 9 for each H II region), and 1.4 GHz continuum observations, of 19 H II regions. These extensive observations allowed us to obtain more precise electron temperature values [in a statistical way similar to that used by Cersosimo, Azcárate and Colomb (1984) for the Carina Nebula] of the low density ionized extended gas associated with these H II regions. Electron densities and emission measures were also obtained (Azcárate 1988).

To improve the statistics, we use in addition results obtained by Pedlar (1980), from H166α observations of low density H II regions and also a determination of the electron temperature in W35 made by Pedlar *et al.* (1978). The antenna beam used in the Pedlar's observations was 36′, similar to that used in ours (34).

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THE OBSERVATIONS

a) *The H166α Line*

The observations were made with the 30-m diameter antenna of the Instituto Argentino de Radioastronomía. The noise temperature of the system was about 85 K for a cold sky background and the half power beam width (HPBW) was $34'$ at 1420 MHz. The frequency switching technique was used in most cases for the observations. The back end included a filter bank of 112 channels of 10 kHz widths, with a velocity resolution of about 2 km s^{-1}. Most of the H II regions were observed at 9 positions each one, at a separation of 0.5°. The total integration time for each position was 4-5 hours. This resulted in a "rms"noise of 0.025 K. The experimental baselines were removed by using, in most of the cases, a second-order polynomial.

b) *The Continuum*

The H II regions were observed in the continuum at 1420 MHz by making several right ascension scans spaced 0.5° in declination. The continuum receiver covered a bandwidth of 40 MHz centered at 1420 MHz. A filter of 2 MHz bandwidth centered at 1420.4057 MHz was used to eliminate the emission from galactic neeutral hydrogen. The receiver was operated in the Dicke switching mode. The velocity of the right ascension scans was 0.5°/minute.

II. RESULTS

We obtained, under the assumption of Local Thermodynamic Equilibrium (LTE), and using the line-to-continuum ratio technique, electron temperatures of 19 H II regions. The observed H II regions were: RCW 108, G 14.25–0.25, Carina, M 17, G 333.3–0.4, RCW 74, RCW 97, G 316.8–0.1, NGC 3603, RCW 131, NGC 6334, RCW 116, W 31, RCW 38, G 338.4+0.0, RCW 122, RCW 49, G 331.5–0.1 and G 13.0+0.0 (W33).

As said above, most of them were observed in several points, about 9 including the central point. We computed also, by using Schraml and Mezger's model (1969), other physical parameters of the sources, such as electron densities and emission measures. The typical electron density and emission measure values are $\simeq$ 2 orders of magnitude lower than those obtained from higher frequency recombination line observations (Wilson *et al.* 1970; Mc Gee and Newton 1981; and other authors). This discrepancy can be explained by the fact that at the frequency of 1.4 GHz, and with the large beam used by us, we are obtaining the physical

TABLE 1

ELECTRON TEMPERATURES, RMS, EMISSION MEASURES AND GALACTOCENTRIC DISTANCES OF THE OBSERVED SOURCES

Source	T_e^* (K)	E.M. (pc cm^{-6})	D_{GC} (kpc)
RCW 108	5000 ± 500	2.4×10^3	8.12
G14.25–0.25	2900 ± 300	···	6.0
Carina	5000 ± 500	4.0×10^3	9.5
M17	5000 ± 500	1.04×10^4	7.8
G 333.3–0.4	5200 ± 500	8.0×10^3	6.75
RCW 74	4500 ± 500	8.77×10^3	8.47
RCW 97	5500 ± 500	8.27×10^3	7.92
G 316.8–0.1	7500 ± 700	4.75×10^3	8.37
NGC 3603	7100 ± 700	6.29×10^3	10.34
RCW 131	8100 ± 800	1.40×10^4	9.0
NGC 6334	5700 ± 600	1.28×10^4	8.28
RCW 116	6400 ± 600	3.78×10^3	8.12
W31	5600 ± 500	3.10×10^3	7.57
RCW 38	8000 ± 800	1.13×10^4	10.04
G 338.4+0.0	6200 ± 600	8.44×10^3	7.04
RCW 122	6000 ± 600	2.81×10^3	8.05
RCW 49	5650 ± 500	6.12×10^3	10.3
G 331.5–0.1	5750 ± 600	3.58×10^3	5.3
W33 (G13.00+0.0)	3700 ± 400	2.02×10^3	4.4

a. T_e is the LTE electron temperature, E.M. is the emission measure, and D_{GC} is the galactocentric distance.

parameters corresponding to the outer, low-density extended parts of the nebulae.

The computed electron temperatures, "rms"emission measures and the galactocentric distances of the sources, are given in Table 1.

The electron temperatures obtained from these observations, together with those of Pedlar (1980) and Pedlar *et al.* (1978), using 34 sources, are plotted in Figure 1, against the galactocentric distance. A linear least-squares fit to the data gives:

$$T_e \;=\; 178.94 D_{GC} + 3920.9$$

The correlation coefficient is 0.39.

The gradient value (178.9±40 kpc^{-1}) is somewhat smaller than that obtained from other radio recombination line surveys, including our previous paper with 27 sources (Azcárate *et al.* 1985). This fact, and the uncertainty (the quoted errors) in the value of the gradient could be caused by some inhomogeneity in the sample of H II regions (different electron densities ranging from $\simeq$ 1 to 20 cm^{-3}), although all the regions considered here have low density. The H II regions with higher electron densities have in general, larger temperatures than the lower density regions, at the same galactocentric distance, being the difference of electron densities a second order factor in the variation of electron temperatures, (the first order factor is the galactocentric distance). Furthermore, the differences in the effective temperatures of the exciting stars cause changes in the electron temperature (Shaver *et al.* 1983).

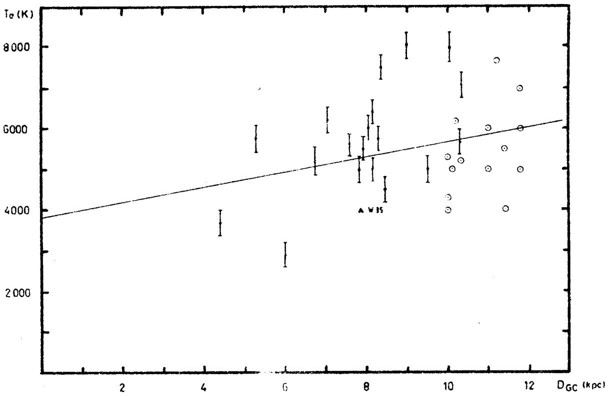

Fig. 1. T_e plotted against galactocentric distance. The full circles with the error bars represent the results of our extensive observations. Open circles with a dot are the values obtained by Pedlar (1980). The straight line is the best fit to the data.

One could try to fit the data shown in Figure 1 by a curve of higher order (this is suggested by the figure), but it would not be suitable due to the observational errors involved, and the effect caused by the fact that Pedlar's low density regions are in the second and third quadrant regions, and our sources are mostly in the fourth quadrant, so the contribution to the measured continuum from nonthermal galactic plane continuum radiation may be quite different for the two cases. The different contribution for the galactic plane could cause a difference in the estimated electron temperatures.

Anyway, the present results are an additional evidence for the existence of a galactic electron temperature gradient for low density ionized gas. The most acceptable explanation for the existence of the temperature gradient is the presence of a galactic abundance gradient (Shaver *et al.* 1983, and other authors) of the coolant ions, such as C, N, O, S ions with the galactocentric distance. This metallicity gradient affects the cooling and hence the electron temperature.

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