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A GALACTIC ELECTRON TEMPERATURE GRADIENT FOR THE EXTENDED AND LOW-DENSITY GAS, DERIVED FROM H166α OBSERVATIONS

I.N. Azcárate*, J.C. Cersosimo** and F.R. Colomb*

Instituto Argentino de Radioastronomía
Argentina

RESUMEN. Se presentan observaciones de varias regiones HII en la línea H166α. Usando la aproximación E.T.L., se deducen las temperaturas electrónicas. Estos valores de T_e* se usan junto con los derivados por Pedlar (1980), de observaciones de H166α, con un haz de antena similar, para deducir un gradiente en la temperatura electrónica con la distancia galactocéntrica. El valor del gradiente obtenido, (310 K kpc^{-1}) está en buen acuerdo con los deducidos de relevamientos de diferentes líneas de recombinación.

ABSTRACT. Observations of several southern HII regions in the H166α line, are reported. Using the LTE approximation, the electron temperatures (T_e*) are derived. These T_e* values are used together with those derived by Pedlar (1980) from H166α observations, with a similar antenna beam, to derive a gradient in the electron temperature with the galactocentric distance. The gradient obtained, (310 K kpc^{-1}) is in good agreement with those derived from surveys in other recombination lines.

I. INTRODUCTION

From surveys of radio recombination lines made at 5 GHz, Churchwell and Walmsley (1975) suggested that the electron temperature, T_e, of HII regions increases with galactocentric distance. They also suggested that the temperature gradient was due to a gradient in the abundance of metals such as C, N, O, S, as it is observed in some Scd galaxies. The relative abundance of these elements affects the cooling and hence the electron temperature. From newer surveys of H109α (Churchwell *et al.* 1978), H110α (Downes *et al.* 1980), H66α (Wilson *et al.* 1979), H86α (Lichten *et al.* 1979), H76α (Mc Gee and Newton 1981, Wink *et al.* 1983), and H125α lines (Garay and Rodríguez 1983) and some observations of β lines (Churchwell *et al.* 1978, Lichten *et al.* 1979), additional evidence for a gradient was obtained.

These radio results find some support from optical measurements. Peimbert *et al.* (1978), using O III, report a gradient of 1100 K kpc^{-1} for 5 HII regions. This value is uncertain because of the small number of sources, however it is in the same sense as in the radio surveys.

Peimbert *et al.* (1978) also directly measured a heavy element gradient with galactocentric distance.

The aim of this paper is to determine whether a temperature gradient results from the H166α line and the 1.4 GHz continuum observations, using the line-to-continuum ratio technique.

To this end, we use results from our observations of 12 HII regions and, to improve the statistics, those reported by Pedlar (1980) from extended and low density HII regions, also observed in the H166α line, with a similar antenna beam to ours, and also a determination of Pedlar *et al.* (1978).

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* Member of the Carrera del Investigador Científico y Tecnológico del Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina.

** Fellow of the CONICET, Argentina.

II. THE OBSERVATIONS

The observations were carried out with the 30 meter-diameter antenna of the Instituto Argentino de Radioastronomía. At 21 cm the telescope has a HPBW of 34 arcmin. The system noise at cold sky background is ≃ 85 K. The spectral analysis was achieved with a bank of 112 filters of 10 KHz width. Both the load and frequency switching techniques were used to perform the observations. The total integration time for each position was, typically, 4 hours with a *r.m.s.* value of about 0.025 K. The final profiles were obtained by removing baseline effects, using in most cases, only second order polynomials.

III. RESULTS

We obtained, under the assumption of Local Thermodynamical Equilibrium (LTE), electron temperature (T_e*) from the H166α line and the 1.4 GHz continuum observations of 12 HII regions: RCW49 (G284.3,-.3), Carina (G287.5,-.5), NGC 6303 (G291.6,-5), RCW74 (G305.4,+.2), G316.8,-.1, RCW 108 (G336.5,-1.5), G338.4, 0.0, NGC 6334 (G351.4,+.7), G10.2,-.3, G13.0,0.0 (W33), G14.25,-.5, M17 (G15.0,-.7). We computed also, using Mezger and Schraml's (1969) equations, some other physical parameters such as *r.m.s.* electron density and emission measure. Observed line and continuum parameters are shown in Table 1, together with the computed emission measures, electron temperatures and galactocentric distances of the regions.

The typical values of electron density (5-30 cm^{-3}) and emission measure (10^3-$7x10^4$ pc cm^{-6}) are in most cases two orders of magnitude lower than the values obtained by other authors at higher frequencies and with smaller beams (e.g., Wilson *et al.* 1970: 5 GHz and 4 arcmin, respectively). This is explained by the fact that, at the frequency of 1.4 GHz and with our large beam (34 arcmin), we are obtaining the physical parameters of the outer and lower density envelopes of the nebulae, in contrast with observations at higher frequencies, which are more sensitive to compact and high emission measure gas near the center of the HII regions.

To improve the statistics, we used published results of Pedlar (1980), corresponding to several extended low density northern HII regions observed in the H166α line with an antenna beam of 36 arcmin (similar to that of the IAR). These regions are either in the local arm or in the Perseus arm (D_{GC} ≃ 11.5 kpc, where D_{GC} is the galactocentric distance).

Low frequency recombination line measurements of W35 (Pedlar *et al.* 1978) indicate its temperature to be 4000 K.

Our regions are rather extended and, as said above, we are obtaining physical parameters that correspond to the low density and extended gas associated, with those regions. The denser and higher emission measure gas near the center of the nebulae becomes optically thick at 1.4 GHz and suffers greater beam dilution.

The T_e* values obtained from our observations, together with those given by Pedlar (1980), and Pedlar *et al.* (1978), are plotted against galactocentric distance in Fig. 1. A linear least-squares fit to the data gives

$$T_e^* = 2624 + 310\, D_{GC} \qquad (1)$$

The correlation coefficient is 0.6. Therefore, it is apparent that a gradient in the electron temperature with galactocentric distance is present for low-to-moderate density ionized gas, as it is shown by these H166α observations and also Garay and Rodríguez (1983), from results in the H125α line.

From Fig. 1, it can be seen that the T_e* values obtained by us in the range 10-12 kpc, are somewhat larger than Pedlar's values, which show a great dispersion for the same range of galactocentric distance. The two regions we observed in the range 10-12 kpc (G284.3,-3, G291.6,-.5) are in the fourth quadrant, therefore the continuum temperatures suffer a non-negligible contribution of galactic non-thermal continuum radiation, which is difficult to estimate. For this reason, it is possible that we are overestimating the continuum temperatures and obtaining higher values of T_e*. Besides, the regions observed by Pedlar (1980) are, most of them, in the second and third quadrants (local and Perseus spiral arms), where non-thermal contributions are smaller than those affecting the continuum temperatures of our sources.

Although the Fig. 1 could suggest that the gradient may not be constant over the considered range of galactocentric distances, it would not be suitable to try to fit the data by a higher order curve, in view of the observational errors involved and also to the effect caused by the fact, already mentioned, that Pedlar's observations refer to the second and third quadrant regions, whereas our sources are mostly in the fourth quadrant, so and the contribution to the continuum from non-thermal sources as we have said, may be different for the two cases. If

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TABLE 1

Source	$\int T_L d_V$ (K km/s)	Continuum Temperatures T_c (K)	LTE Electron Temperatures T_e^* (K)	Mean LSR Velocities V_{LSR}(km/s)	Emission Measures E.M. (pc cm^{-6})	Galactocentric Distances D_{GC} (kpc)
RCW 49 (G 284.3,-.3)	14.04	41	7600±700	- 2	2.16×10^4	10.3
Carina (G 287.5,-0.5)	20.92	50	6500±600	-22	4×10^3	9.5
NGC 6303 (G 291.6,-0.5)	9.68	30	7800±800	+10	8.21×10^3	10.34
RCW 74 (G 305.4,+0.2)	14.14	27	5100±500	-38	7×10^4	8.47
G 316.8,-10	5.28	15	6800±700	-42	2.5×10^3	8.37
RCW 108 (G 336.5,-1.5)	2.93	5.5	5000±500	-20	2.4×10^3	8.12
G 338.4,0.0	10.10	17	4600±500	-32	4.9×10^3	7.04
NGC 6334 (G351.4,+0.7)	14.53	27	5000±500	- 4	2.95×10^4	8.28
G 10.2,-0.3	6.22	14	5700±600	+10	6.11×10^4	7.57
G 13.0,0.0 (W 33)	3.73	5	3700±400	+32	2.02×10^3	4.4
G 14.25,-0.5	4.08	3.5	2900±300	+30		6
M 17 (G 15.0,-0.7)	25.95	60	6100±600	+20	1.16×10^4	7.8

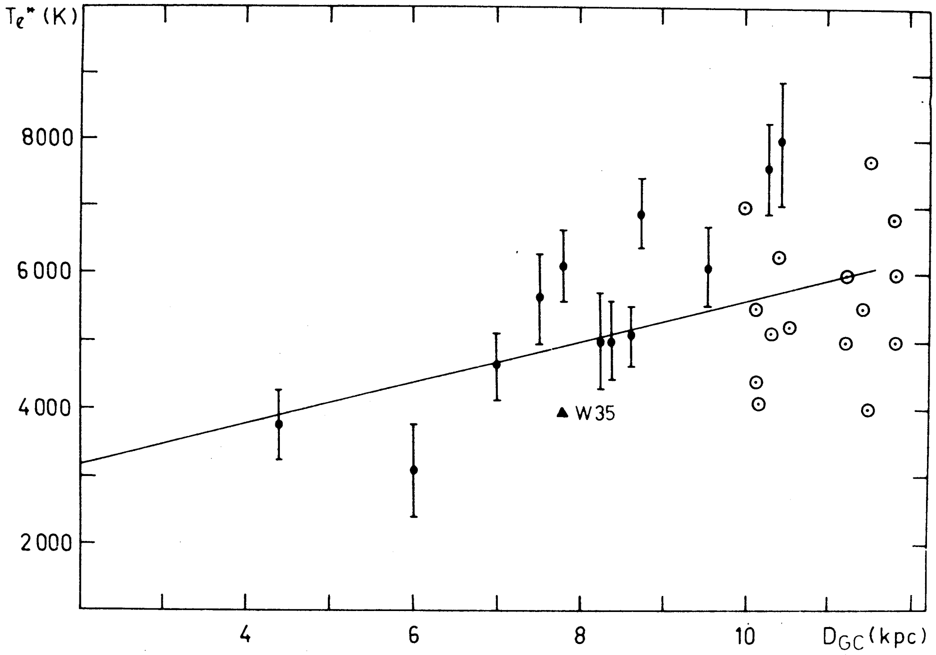

Fig. 1. T_e* plotted against galactocentric distance. The full circles represent the results of our observations. The open circles with a doth within are the values obtained by Pedlar (1980). The straight line corresponds to the best fit to the data.

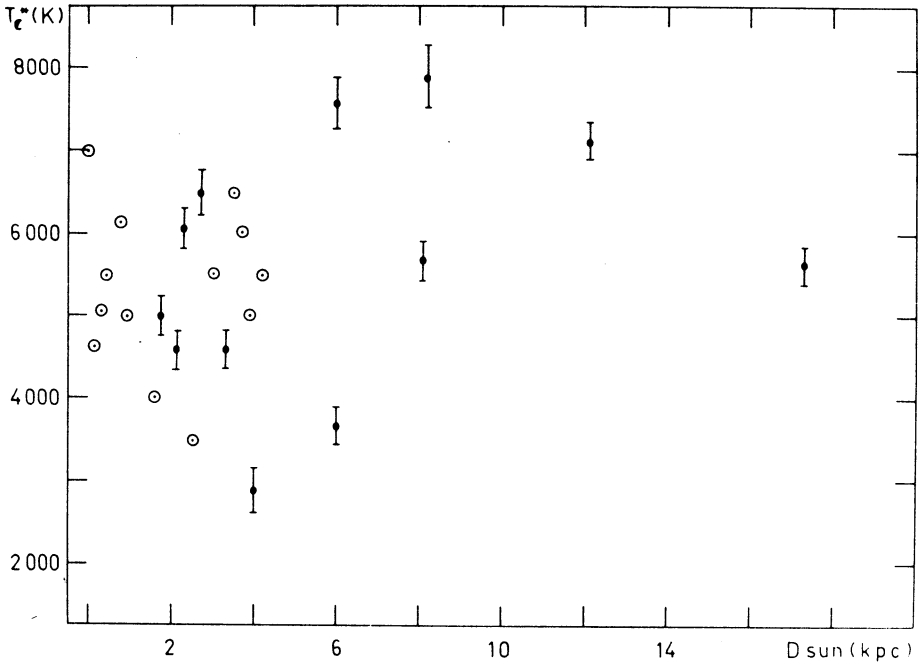

Fig. 2. T_e* plotted against the distance from the Sun (D_{SUN}).

TABLE 2

STATISTICAL RESULTS IN DIFFERENT FREQUENCIES

A*(K)	B*(K kpc^{-1})	Line	Frequency (GHz)	Angular Resolution (arc min)	N° of sources	References
4500	310	H109α	5.0	2.6	36	Churchwell *et al.* (1978)
5534	250	H137β	5.0	2.6	30	Churchwell *et al.* (1978)
4700	380	H86α	10.2	3.5	20	Lichten *et al.* (1979)
6000	250	H108β	10.2	3.5	20	Lichten *et al.* (1979)
5000	300	H66α	22.4	0.7	19	Wilson *et al.* (1979)
4600	340	H110α	5.0	2.6	133	Downes *et al.* (1980)
3900	430	H76α	14.7	2.3	25	McGee and Newton (1981)
4788	268	H76α	14.7	1.0	72	Wink *et al.* (1983)
3000	440	H125α	3.3	10.0	23	Garay and Rodríguez (1983)
2624	310	H166α	1.42	34.00,36.0	27	Present paper, using also values from Pedlar (1980)

* From $T_e^* = A + B\ D_{GC}$

we only take the results of our observations and try to fit a straight line through them, we would obtain a value of the gradient of about 1000 K kpc^{-1}. The sample is, however, small -only 12 regions- and in order to improve the statistics and attempt a determination of the temperature gradient with only observations of ours we are at present carrying out further observations at the IAR.

We have also plotted the electron temperatures derived from our observations and those of Pedlar, against distance from the Sun (see Fig. 2). The relationship derived from a least-squares fit to the data is

$$T_e^* = 4788 + 127\, D_{\mathrm{Sun}} \qquad (2)$$

The correlation coefficient is 0.24, showing that there is no significant correlation. This also happens in other recombination line surveys (Churchwell *et al.* 1978, Wilson *et al.* 1979, Lichten *et al.* 1979).

IV. DISCUSSION

The value of the T_e^* gradient in HII regions, derived by us, is in good agreement with those obtained from observations of other recombination lines (see Table 2). This gradient is shown to be present also for low-to-moderate density ionized gas, according to the results of this paper and those of Garay and Rodríguez (1983), from the H125α line. Most of the results shown in Table 2 correspond to high electron density gas ($N_e \gtrsim 1000$ cm-3). Only our results and those of Garay and Rodríguez (1983) correspond to low electron density gas ($N_e \simeq 5 - 30$ cm-3). We can see from this Table that the temperatures of the high density ionized gas are systematically larger than those of the lower density gas at any galactocentric distance. This can be attributed to the presence of collisional de-excitation in the dense gas, a process that inhibit cooling (Garay and Rodríguez 1983). This effect could be larger if there are, in the dense gas (N_e *rms* $\simeq 1000\ \mathrm{cm}^{-3}$) clumps of even higher density of about $10^4\ \mathrm{cm}^{-3}$ (Cersosimo and Loiseau 1984).

Lockman and Brown (1978) have argued that the observed gradient in T_e^* in several recombination line surveys, might be a selection effect which causes an apparent variation of T_e^* with distance from the Sun, eventhough the true electron temperature T_e^* is constant. A decrease in T_e^* with increasing distance from the Sun would mimic an increase in T_e^* with distance from the galactic center. But the lack of correlation between T_e^* and distance from the Sun, and the reasonable agreement on the values of the gradient for different frequencies, support the hyphotesis that a T_e^* gradient does exist.

In regard to the role played by the metal abundance, Hawley (1978) from a survey of 15 HII regions between 8 and 14 kpc from the galactic center, has found a gradient in the abundance ratios of $|N| / |H|$ and $|O| / |H|$. Peimbert and Torres Peimbert (1974) have argued that the value of the gradient in $|O| / |H|$ should represent a gradient in the metal abundance. The value of the gradient in $|O| / |H|$, found by Hawley (1978), agrees with the gradient for the metals derived by Churchwell *et al.* (1978). As it is stated in the introduction of this paper, the relative abundance of the metals (C, N, O, S) affects the cooling and hence the electron temperature. That seems to be the most acceptable explanation for the presence of a gradient of the electron temperature with the galactocentric distance.

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REFERENCES

Churchwell, E. and Walmsley, C.M. 1975, *Astron. Ap.* 38, 451.
Churchwell, E., Smith, L.F., Mathis, J., Mezger, P.G., and Huchtmeier, W. 1978, *Astron. Ap.* 70, 719.
Cersósimo, J.C. and Loiseau, N. 1984, *Astron. Ap.* 133, 93.
Downes, D., Wilson, T.L., Bieging, J., and Wink, J. 1980, *Astron. Ap. Suppl.* 40, 379.
Garay, G. and Rodríguez, L.F. 1983, *Ap. J.* 266, 263.

Hawley, S.A. 1978, *Ap. J.* 224, 417.
Lichten, S.M., Rodríguez, L.F. and Chaison, E.J. 1979, *Ap. J.* 229, 524.
Lockman, F.J. and Brown, R.L. 1978, *Ap. J.* 222, 153.
McGee, R.X. and Newton, L.M. 1981, *M.N.R.A.S.* 196, 889.
Pedlar, A., Davies, R.D., Hart, L. and Shaver, P.A. 1978, *M.N.R.A.S.* 182, 473.
Pedlar, A. 1980, *M.N.R.A.S.* 192, 179.
Peimbert, M. and Torres-Peimbert, S. 1974, *Ap. J.* 193, 327.
Peimbert, M., Torres-Peimbert, S., and Rayo, J.F. 1978, *Ap. J.* 220, 516.
Schraml, J., and Mezger, P.G. 1969, *Ap. J.* 156, 269.
Wilson, T.L., Mezger, P.G., Gardner, F.F., and Milne, D.K. 1970, *Astron. Ap.* 7, 364.
Wilson, T.L., Pauls, T.A. and Ziurys, L.M. 1979, *Astron. Ap.* 77, L3.
Wink, J.E., Wilson, T.L., and Bieging, J.H. 1983, *Astron. Ap.*, in press.

DISCUSSION

Peimbert: Uno esperaría una menor temperatura electrónica en las regiones HII de menor densidad. ¿Es posible a partir de su muestra encontrar este efecto?

Azcárate: Sí, el gradiente es parecido, y las temperaturas electrónicas son sistemáticamente más bajas que en regiones HII de alta densidad.

Ismael N. Azcárate, Juan C. Cersósimo and Fernando R. Colomb: Instituto Argentino de Radioastronomía, Casilla de Correo 5, 1894 Villa Elisa, Provincia de Buenos Aires, Argentina.