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OXYGEN AND HELIUM ABUNDANCES IN GALACTIC H II REGIONS: ABUNDANCE GRADIENTS

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RESUMEN

Se han medido y analizado los flujos integrados absolutos en las líneas [O II] $\lambda3726$ y $\lambda3729$, [O III] $\lambda4363$ y $\lambda5007$, He I $\lambda5876$, Hα y Hβ, de 34 regiones H II galácticas, con distancias galactocéntricas, $R_{\rm G}$, entre 6.6 y 17.7 kpc. Se han derivado las condiciones físicas, las abundancias iónicas O^+/H^+, O^{++}/H^+ y He^+/H^+ y la abundancia total de oxígeno de las regiones. Se determinaron temperaturas electrónicas precisas para 6 regiones con $R_{\rm G}$ entre 6.6 kpc y 14.8 kpc, ampliando el intervalo para el cual existen tales medidas. Encontramos una relación entre O/H y $R_{\rm G}$ de la forma $12+\log {\rm O/H} = (-3.95\pm0.49)\times10^{-2}R_{\rm G}+(8.82\pm0.05)$. El gradiente encontrado es menor, por un factor de 2, que el gradiente reportado por Shaver et al. (1983). No encontramos evidencia de un aplanamiento del gradiente hasta $R_{\rm G} = 15$ kpc. Nuestras mediciones de He^+/H^+ muestran que puede haber cantidades importantes de helio neutro aun en el caso de regiones ionizadas por estrellas más tempranas que O 6.5. Para las regiones con buena determinación de He/H, encontramos un alto valor de $\Delta Y/\Delta({\rm O/H})$.

ABSTRACT

Absolute integrated fluxes have been obtained for 34 H II regions, with Galactocentric distances $R_{\rm G}$ in the 6.6–17.7 kpc range, in the emission lines [O II] $\lambda3726$ and $\lambda3729$, [O III] $\lambda4363$ and $\lambda5007$, He I $\lambda5876$, Hα and Hβ. These fluxes are analyzed to derive the physical parameters, the ionic abundances O^+/H^+, O^{++}/H^+ and He^+/H^+ and the O/H abundances. Accurate electron temperatures have been derived in six H II regions with $R_{\rm G}$ between 6.6 kpc and 14.8 kpc, widening the $R_{\rm G}$ range for which reliable $T_{\rm e}$ measurements exist. Our O/H relationship for 5 kpc $< R_{\rm G} <$ 15 kpc is $12 + \log {\rm O/H} = (-3.95 \pm 0.49) \times 10^{-2} R_{\rm G} + (8.82 \pm 0.05)$. The slope is lower, by a factor of two, than that previously obtained by Shaver et al. (1983). No significant flattening of this relation is obtained out to 15 kpc. Our helium observations show that even a region ionized by a star earlier than O 6.5 may contain a significant amount of neutral helium. We confirm the high $\Delta Y/\Delta({\rm O/H})$ value ($\geq$180) measured in the Galaxy.

Key Words: **GALAXY: ABUNDANCES — H II REGIONS — ISM: ABUNDANCES**

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1. INTRODUCTION

Absolute integrated fluxes have been obtained for 34 H II regions, with Galactocentric distances, $R_{\rm G}$, in the 6.6–17.7 kpc range, using the 1.5-m telescope at OAN, SPM, equipped with the *ESOP* Fabry-Perot spectrophotometer. The instrumentation and the observations are described in Caplan et al. (2000) and a full discussion of this work can be found in Deharveng et al. (2000).

Our aim is to measure the oxygen and helium abundances of numerous Galactic H II regions, and then use these results to discuss the Galactic oxygen abundance gradient and the $\Delta Y/\Delta({\rm O/H})$ ratio. Thus, the observed H II regions were selected to satisfy either of the following criteria: they are excited by very hot stars

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(spectral type $\sim$ O5 or O6), or they are smaller than our largest diaphragm ($4'27''$). For the extended objects, several zones, at different distances from the exciting stars, have been observed.

Also in Caplan et al. (2000) are descriptions of the observed regions, the spectral types and color excesses of their exciting stars and a discussion of their Galactocentric distances. The latter parameter is very important for determining abundance gradients. Therefore, we have recalculated the photometric distances for all the objects in a consistent manner.

The emission lines [O II] 3726 and 3729, [O III] 5007, He I 5876, Hα, Hβ and Hδ were measured for most of the objects. The faint [O III] 4363 line was measured only in six H II regions: M16, M42 (Orion Nebula), Sh117, Sh184, Sh206 and Sh212.

Temperatures and abundances can be calculated from the emission lines after correcting for reddening. Therefore, data were analyzed to derive the extinctions. Remarkably, we have found a very good agreement, over a large range of visual extinction, between the color excesses, $E(V-B)$, derived from the Balmer decrements and those measured for the exciting stars (see Fig. 1 by Deharveng et al. 2000). This suggests that reddening is produced mostly by standard, uniformly-distributed dust outside of the actual H II regions.

2. PHYSICAL CONDITIONS: DENSITIES AND TEMPERATURES

Electron densities were derived from the [O II] 3726/3729 line ratios. All the densities are in the 100–1000 cm^{-3} range, except in the Orion Nebula where $N_{\rm e} \sim 3500$ cm^{-3}. These values were used to determine electron temperatures and ionic abundances.

The electron temperature is the most important parameter for deriving confident chemical abundances from collisionally excited lines. In our work, $T_{\rm e}$ has been derived from the [O III]4363/5007 intensity ratio in the six regions mentioned above and the results are presented in Table 1. Our values are in good agreement with measurements from radio recombination lines. The regions with measured $T_{\rm e}$ are located at Galactocentric distances between 6.6 kpc and 14.8 kpc, which widens the $R_{\rm G}$ range for which reliable $T_{\rm e}$ measurements exist. In this sense, our measurement for Sh 212, located at 14.8 kpc from the galactic center is extremely important.

TABLE 1

PHYSICAL PARAMETERS OF THE SIX H II REGIONS WITH MEASURED $T_{\rm E}$.

Name	RA 1950	Dec 1950	$R_{\rm G}$ (pc)	$T_{\rm e}$ (K)	$N_{\rm e}$ (cm^{-3})	E_{B-V} (mag)	O/H $\times 10^4$	He$^+$/H$^+$ $\times 10^2$
M 16 (Sh 49)	18 15 57.9	−13 54 13	6600	6833	71	0.615	3.43	9.33
Sh 117	20 55 46.8	+44 38 50	8500	7120	16	0.149	3.29	9.27
Sh 184	00 49 53.1	+56 21 20	10100	7960	116	0.368	2.54	9.96
Sh 206	03 59 34.8	+51 10 37	11100	9010	502	1.320	2.50	10.36
Sh 212	04 36 47.7	+50 21 53	14800	9660	128	0.921	1.81	10.14
M 42 (Orion)	05 32 45.0	−05 25 16	8800	8360	3665	0.166	3.26	9.82

Our study, as many other similar studies in the literature (e.g., the radio studies by Mezger et al. 1979; Wink, Wilson, & Bieging 1983; Shaver et al. 1983; Caswell & Haynes 1987), demonstrates the existence of a gradient of electron temperature in the Galaxy, with $T_{\rm e}$ increasing with distance from the center.

Combining our $T_{\rm e}$([O III]) results with the radio studies mentioned before, we obtain the following temperature relationship for the Galaxy

$$T_{\rm e}\ [{\rm K}] = (372 \pm 38) R_{\rm G} + 4260 \pm 350.$$

3. OXYGEN ABUNDANCES

O$^+$/H$^+$ and O^{++}/H$^+$ ionic abundances have been derived assuming a two-temperature H II region model. $T_{\rm e}$([O III]) was adopted for O^{++} and $T_{\rm e}$ for O$^+$ was obtained from a grid of photoionization models by Stasińska & Schaerer (1997).

From the ionic abundances, the total O abundance was obtained from $O/H = O^+/H^+ + O^{++}/H^+$. The O abundances combined with the galactocentric distances, for our six objects with good abundance determination plus two well studied objects from the literature (M17 from Peimbert, Torres-Peimbert, & Ruiz 1992; and Sh298 from Esteban et al. 1990), produce the following O/H vs. R_{G} relationship for 5 kpc $< R_{\mathrm{G}} <$ 15 kpc

$$12 + \log \mathrm{O/H} = (-3.95 \pm 0.49) \times 10^{-2} R_{\mathrm{G}} + (8.82 \pm 0.05).$$

Our main results, derived from this equation, are:

1.- The slope is lower, by a factor of two, than that previously obtained by Shaver et al. (1983).

2.- Contrary to previous results (e.g., Vílchez & Esteban 1996) no significant flattening of this relation is obtained out to 15 kpc.

3.- At the solar Galactocentric distance, $12 + \log(\mathrm{O/H}) = 8.48$, in good agreement with the O/H value measured in the local interstellar medium (Meyer, Jura, & Cardelli 1998), and a factor of two lower than the solar abundance.

4. HELIUM ABUNDANCES

He^+/H^+ abundances were derived from the He I 5876/Hβ ratio, adopting the [O III] temperature and using the recent (collisional-excitation corrected) He I λ5876 emissivities by Benjamin, Skillman, & Smits (1999). In the case of extended objects, the ionic abundances were measured in several zones with different distances from the exciting stars.

Our helium observations show that even a region ionized by a star earlier than O 6.5 may contain a significant amount of neutral helium, in contradiction with results from photoionization model predictions (cf. Stasińska & Schaerer 1997). Therefore, we were able to measure accurate total He/H abundance ratios in only Sh206 (He/H = 0.1036) and, probably, Sh212 (He/H = 0.1014), while the values presented in Table 1 for M42 (Orion Nebula) and Sh184 are lower limits of their true He/H abundance ratios.

Considering our difficulty in obtaining a good measurement of He/H in rather simple individual Galactic H II regions, we believe that the accuracy of the He/H results in low-metallicity galaxies, which rely on the integrated emission of numerous H II regions included in the spectrograph slit is very often overestimated.

From our He/H and O/H ratios, we obtain high $\Delta Y/\Delta(\mathrm{O/H})$ values (in the range 180 − 220, assuming $Y_{\mathrm{P}} = 0.235$), thus confirming the high value previously found by Peimbert et al. (1992) in the Galaxy.

Our observational data were collected at the Observatorio Astronómico Nacional, SPM, B.C., México. L.D. and J.C. greatly appreciated the hospitality of the observatory staff. This research has made use of the Simbad database, operated at CDS, Strasbourg, France. We especially thank Claire Blondel for her essential aid with the instrumentation and the observations. This work was partially supported by DGAPA/UNAM IN-109696.

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