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O II RECOMBINATION LINES AND TEMPERATURE FLUCTUATIONS IN M8 AND M17

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RESUMEN

Presentamos resultados preliminares del análisis de espectros echelle de la nebulosa de la Laguna (M8) y la nebulosa de Omega (M17). Los datos se obtuvieron con el telescopio de 2.1-m del Observatorio Astronómico Nacional en San Pedro Mártir. Detectamos y medimos varias líneas individuales de recombinación de O^+ y C^+. Hemos calculado la abundancia de O^{++}/H^+ utilizando diferentes multipletes y eliminando el problema de la superposición de líneas. La abundancia de O^{++}/H^+ obtenida a partir de líneas de recombinación resulta ser superior al valor calculado usando las líneas de [O III] del mismo espectro, un factor 2 en M8 y 2.4 en M17. Por otro lado, en el caso de M8, el cociente C^{++}/H^+ obtenido a partir de la línea permitida C II λ4267 Å es un factor 3.5 superior al calculado para la misma zona en un trabajo anterior utilizando C III] $\lambda\lambda$1906+1909 Å. Estimamos que un valor de la fluctuación espacial de temperatura de $t^2 = 0.039 \pm 0.015$ para M8 y $t^2 = 0.045 \pm 0.022$ para M17 puede explicar las discrepancias.

ABSTRACT

We present preliminary results on the analysis of echelle spectra of the Lagoon nebula (M8) and the Omega nebula (M17). The data were obtained using the 2.1-m telescope at the Observatorio Astronómico Nacional on San Pedro Mártir. We have detected and measured individual recombination lines of O^+ and C^+. We have derived O^{++}/H^+ value using several multiplets and avoiding the problem of line blending. The O^{++}/H^+ abundance obtained from recombination lines is larger than that derived using forbidden [O III] lines from the same spectrum, a factor of 2 in the case of M8 and of 2.4 in the case of M17. On the other hand, in the case of M8, the C^{++}/H^+ value derived using the permitted C II λ4267 Å line is a factor of 3.5 higher than that quoted in previous work for the same zone using C III] $\lambda\lambda$1906+1909 Å emission lines. We estimate that values of the spatial temperature fluctuations given by $t^2 = 0.039 \pm 0.015$ for M8 and $t^2 = 0.045 \pm 0.022$ for M17 can account for these discrepancies.

Key words: **H II REGIONS — ISM: ABUNDANCES — ISM: INDIVIDUAL OBJECTS (M8, M17)**

1. INTRODUCTION

The Lagoon nebula (M8) and the Omega nebula (M17) are two of the brightest and most studied Galactic H II regions. There has been a lot of work devoted to study the chemical abundances of these objects (e.g., Peimbert, Torres-Peimbert, & Dufour 1993b; Peimbert, Torres-Peimbert, & Ruiz 1992 and references therein). Traditionally, the abundance studies for H II regions have been based on determinations from forbidden lines, which are strongly dependent on temperature variations over the observed volume. Alternatively, recombination lines are almost independent of such variations and, in principle, they should be more precise indicators of the true chemical abundances (e.g., Peimbert, Storey, & Torres-Peimbert 1993a).

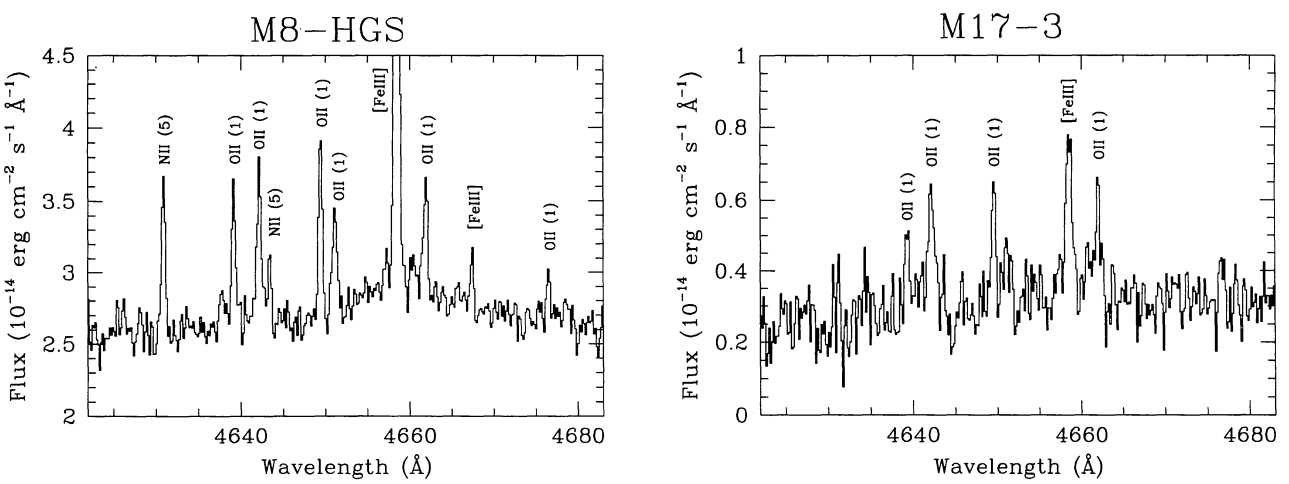

Fig. 1. Sections of the echelle spectra of M8 and M17 showing all the individual emission lines of multiplet 1 of O II.

TABLE 1

O^{++}/H^{+} ABUNDANCE

Multiplet		M8–HGS		M17–3	
		Case A	Case B	Case A	Case B
		($\times 10^{-5}$)		($\times 10^{-5}$)	
M1	Average	23 ± 11	22 ± 11	83 ± 32	80 ± 31
	Sum	18 ± 7	17 ± 7	78 ± 28	75 ± 28
M2	Average	32 ± 14	23 ± 9	...	...
	Sum	29 ± 12	21 ± 8	...	...
M10	Average	21 ± 8	21 ± 8	...	...

We have obtained long exposure CCD high spectral resolution echelle spectrograms to obtain accurate measurements of O II recombination lines and other permitted lines of heavy element ions in the spectra of M8 and M17. The main aim of this work is to determine the O^{++} abundance from individual recombination lines —avoiding the problem of line blending— and to compare it with the value derived using forbidden lines from the same spectrum. A similar comparison can be performed for the C^{++} abundance in M8, but in this case, we have to compare our determinations using recombination lines with those obtained by other authors from UV C III] $\lambda\lambda$1906+1909 Å emission lines (Peimbert et al. 1993b). This work complements a previous similar study of the Orion Nebula (Esteban et al. 1995, 1998)

2. OBSERVATIONS

The observations were carried out at the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir on August 1995. High resolution CCD spectra were obtained using the SPM REOSC Echelle Spectrograph. This instrument gives a resolution of 0.234 Å pixel^{-1} at Hα using the UCL camera and a CCD-Tek chip of 1024 × 1024 pixels. We obtained spectra covering two overlapping wavelength ranges. The blue range covers from 3550 to 5800 Å —26 spectral orders—; and the red range from 4500 to 6850 Å –17 spectral orders. Three and four individual exposures of 20 min. were added to obtain the final blue and red spectra. Slits covering 26.6" × 2" in the red exposures and 13.3" × 2" in the blue ones were used to avoid overlapping between orders. The centers of the slit positions were 12" S of the center of the Hourglass for M8 (zone HGS as defined by Sánchez & Peimbert 1991) and 54" W 250" S of BD–16°4819 (position 3 of Peimbert et al. 1992) for M17. The slit orientation was East–West for all the observations. The absolute flux calibration was made taking an echellogram of a standard star.

TABLE 2

C^{++}/H^+ ABUNDANCE

Multiplet	M8–HGS		M17–3	
	Case A	Case B	Case A	Case B
	($\times 10^{-5}$)		($\times 10^{-5}$)	
M2	47 ± 17	11 ± 4	58 ± 10	13 ± 2
M6	21 ± 6	21 ± 6	40 ± 15	40 ± 15

TABLE 3

t^2 PARAMETER

		Forbidden lines ($t^2 = 0.00$)	Recombination lines	t^2(R/C)
M8	$12+\log(O^{++}/H^+)$	7.97 ± 0.06	8.28 ± 0.15	0.035 ± 0.016
	$12+\log(C^{++}/H^+)$	7.76 ± 0.10^a	8.32 ± 0.13	0.043 ± 0.014
M17	$12+\log(O^{++}/H^+)$	8.49 ± 0.06	8.87 ± 0.18	0.045 ± 0.022
	$12+\log(C^{++}/H^+)$	...	8.60 ± 0.10	...

[a]Derived using C III] $\lambda\lambda$ 1906+1909 Å (Peimbert, Torres-Peimbert, & Dufour 1993b).

3. RESULTS AND DISCUSSION

The reddening coefficient was calculated from the comparison between observed and theoretical Balmer line ratios using the standard reddening law (Whitford 1958) and amounts to $C(H\beta) = 1.02$ and 2.10 for M8 and M17, respectively. These values are similar to those obtained by Sánchez & Peimbert (1991) and Peimbert et al. (1992) for the same position for each nebula. The final useful wavelength interval covers from 3550 Å to 6850 Å. In Figure 1 we present a section of the spectrum showing all the emission lines of multiplet 1 of O II in M8 and M17. At this spectral resolution we can avoid overlapping of the individual lines of the multiplet.

We have derived the physical conditions from forbidden line analysis (electron densities and temperatures) and they are consistent with those obtained in previous works for the same positions in M8 and M17 (e.g., Sánchez & Peimbert 1991; Peimbert et al. 1992).

From the O II recombination lines of the multiplets M1 (3s ^{4}P–3p ^{4}D°), M2 (3s ^{4}P–3p ^{4}P°) and M10 (3p ^{4}D°–3d ^{4}F), we have calculated the O^{++}/H^+ values using the effective recombination coefficients presented by Storey (1994). We find very high internal consistency among the values derived from the three multiplets observed in M8. In Table 1 we show the values of O^{++}/H^+ obtained, for cases A and B, for the average of the abundances obtained from all individual lines (labelled as "Average" in Table 1) as well as the abundance obtained from the sum of the intensities of all the lines of the same multiplet (labelled as "Sum" in the table). For M8, we adopt $O^{++}/H^+ = 19 \pm 6 \times 10^{-5}$, (considering case B and the average of the sum values for multiplets M1 and M2) as representative for the nebula, this abundance is a factor of 2 larger than that obtained using forbidden lines. In the case of M17, we adopt the sum value of M1 for case B, $O^{++}/H^+ = 75 \pm 28 \times 10^{-5}$ which is a factor of 2.4 larger than that obtained using forbidden lines. For M17, we have not considered the intensity of the O II 4649 Å line due to possible underlying stellar absorption. This is supported by an additional echelle spectrum of the most luminous ionizing star of this nebula that shows a relatively strong absorption in the spectral zone around 4650 Å.

The C^{++}/H^+ value has been derived using the C II $\lambda\lambda$4267 Å (M6) and 6578Å (M2) lines and the result is presented in Table 2. For both emission lines we have used the α_{eff} calculated by Péquignot, Petitjean, & Boisson (1991). From the C II λ4267 Å emission line for M8, we obtain a C^{++}/H^+ value a factor of 3.5 higher than that derived by Peimbert et al. (1993b) for the same zone based on the UV C III] λ1906+1909 Å lines. From the observations of 4267/Hβ by Peimbert et al. (1992) we obtain $C^{++}/H^+ = (46 \pm 6) \times 10^{-5}$ for M17; furthermore, we expect the M2 value to be intermediate between cases A and B; therefore, we conclude that $C^{++}/H^+ = (40 \pm 10) \times 10^{-5}$, in agreement with the results presented in Table 2 and the observations of Peimbert et al. (1992).

The difference between the ionic abundances of O^{++} and C^{++} derived from forbidden and recombination lines leads us to calculate the mean-square temperature fluctuation, t^2(R/C), which yields the same abundances for both types of lines (the abundance given by the recombination lines). For M8 this parameter gives a value of 0.035 in the case of O^{++}/H^+ and 0.043 for C^{++}/H^+ (see Table 3). An average of $t^2 = 0.039 \pm 0.015$ for M8 and $t^2 = 0.045 \pm 0.022$ for M17, could be a representative value for the observed zones considering the uncertainties estimated for the abundance determinations. These values of the mean square fluctuation are entirely consistent with previous estimates (Peimbert et al. 1993b; Peimbert et al. 1992) and somewhat larger than the value of $t^2 = 0.024 \pm 0.007$ obtained for the Orion nebula (Esteban et al. 1998).

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REFERENCES

Esteban, C., Peimbert, M., Torres-Peimbert, S., & Escalante, V. 1995, in The Fifth Mexico-Texas Conference in Astrophysics: Gaseous Nebulae and Star Formation, ed. M. Peña & S. Kurtz, RevMexAASC, 3, 241
_____. 1998, MNRAS, in press
Peimbert, M., Torres–Peimbert, S., & Ruiz, M. T. 1992, RevMexAA, 24, 155
Peimbert, M., Storey, P. J., & Torres–Peimbert, S. 1993a, ApJ, 414, 626
Peimbert, M., Torres–Peimbert, S., & Dufour, R. J. 1993b, ApJ, 418, 760
Péquignot, D., Petitjean, P., & Boisson, C. 1991, A&A, 251, 680
Sánchez, L. J., & Peimbert, M. 1991, RevMexAA, 22, 285
Storey, P. J. 1994, A&A, 282, 999
Whitford, A. E. 1958, AJ, 63, 201