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FAINT EMISSION LINES IN THE ORION NEBULA: C AND O ABUNDANCES

César Esteban
Instituto de Astrofísica de Canarias, 38200 La Laguna, Tenerife, Spain
and
Manuel Peimbert, Silvia Torres-Peimbert, and Vladimir Escalante
Instituto de Astronomía, UNAM, Apdo. Postal 70-264, 04510 México D.F., México

RESUMEN

Presentamos resultados preliminares del análisis de espectros echelle de la Nebulosa de Orión tomados a 45″ N de θ^1 Ori C y que cubren desde 3700 hasta 6750 Å. Los datos se obtuvieron con el telescopio de 2.1-m del Observatorio Astronómico Nacional en San Pedro Mártir, B.C. Detectamos y medimos varias líneas permitidas de emisión débiles de O^0, O^+, C^+, S^+, N^+, Si^+ y Si^{++} excitadas por recombinación electrónica y/o fluorescencia. La adecuada relación S/R y resolución espectral de los datos nos permite el cálculo de la abundancia de O^{++}/H^+ utilizando varias líneas de 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 un 40% superior al valor calculado usando las líneas de [O III] del mismo espectro. Por otro lado, el cociente C^{++}/H^+ obtenido a partir de la línea permitida CII λ4267 es un factor de 3 superior a la calculada en un trabajo anterior para la misma zona y utilizando C III] $\lambda\lambda$1906+1909. Estimamos que un valor moderado de t^2=0.025±0.015 podría explicar estas discrepancias.

ABSTRACT

We present preliminary results on the analysis of echelle spectra of the Orion Nebula taken at 45″ N of θ^1 Ori C and covering from 3700 to 6750 Å. The data were obtained using the 2.1-m telescope at the Observatorio Astronómico Nacional in San Pedro Mártir, B.C. We have detected and measured several faint permitted lines of O^0, O^+, C^+, S^+, N^+, Si^+ and Si^{++} which are excited by electron recombination and/or fluorescence. The S/N ratio and spectral resolution of the data are adequate to allow the derivation of O^{++}/H^+ using several lines and avoiding the problem of line blending. The O^{++}/H^+ abundance obtained from recombination lines is 40% higher than that derived using forbidden [O III] lines from the same spectrum. On the other hand, the C^{++}/H^+ value derived using the permitted C II λ4267 line is a factor of 3 higher than that quoted in previous work for the same zone using C III] $\lambda\lambda$1906+1909 emission lines. We estimate that a moderate value of t^2=0.025±0.015 can account for these discrepancies.

Key words: **H II REGIONS — ISM: INDIVIDUAL OBJECTS: THE ORION NEBULA — ISM: ABUNDANCES**

1. INTRODUCTION

The Orion Nebula is the most observed galactic H II region. There has been a great deal of work devoted to the study of the chemical abundances of this object (e.g., Peimbert & Torres-Peimbert 1977). 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. Recombination lines, on the other hand, are almost independent of such variations and, in principle, should be more precise indicators of the true chemical abundances. Recently, Peimbert, Storey, & Torres-Peimbert (1993) derived O^{++}/H^{+} values from O II line intensities by Osterbrock, Tran, & Veilleux (1992) finding that they are a factor of 2 larger than the O^{++}/H^{+} values obtained using forbidden lines. This discrepancy can be interpreted in terms of temperature fluctuations with a $t^2 \approx 0.040$.

We have obtained long exposure, high spectral resolution, CCD echelle spectrograms to obtain accurate measurements of O II recombination lines and other permitted lines of heavy element ions in the spectrum of the Orion Nebula. The main aims of this work are to determine the O^{++} abundance from individual recombination lines (avoiding the problem of line blending), and to compare this with the value derived using forbidden lines from the same spectrum. A similar comparison can be performed for the C^{++} abundance, by comparing our recombination line determinations with values obtained by other authors from the UV C III] $\lambda\lambda$1906+1909 emission lines (Walter, Dufour, & Hester 1992).

2. OBSERVATIONS

The observations were carried out at the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir in October 1994. High resolution CCD spectra were obtained using the SPM REOSC Echelle Spectrograph. This instrument gives a resolution of 0.185 Å pixel^{-1} at Hα using the UCL camera and a Thompson CCD chip of 1024×1024 pixels. We obtained spectra covering two overlapping wavelength ranges. The blue range covers from 3400 to 5375 Å (23 spectral orders); and the red one covers from 4500 to 6850 Å (18 spectral orders). Four and five individual exposures of 20 minutes each were added to obtain the definitive blue and red spectra. A slit covering 26.6″×2″ in the red and 13.3″×2″ in the blue was used to avoid overlapping between orders. The slit position was 45″ North of θ^1 Ori C, oriented East–West during all the observations. The absolute flux calibration was made taking an echellogram of a single standard star.

3. RESULTS AND DISCUSSION

Almost 200 emission lines were detected, measured and identified in the observed spectrum. The complete list will be published elsewhere (Esteban et al. 1995). The useful wavelength interval ranges from 3700 to 6850 Å. We reject the zone between 3400 and 3700 Å due to the lower response of the chip in the blue and the low count number collected for the standard star at those wavelengths. The logarithmic reddening coefficient al Hβ was calculated from the comparison between observed and theoretical Balmer line ratios using the reddening law derived by Costero & Peimbert (1970) and gives a value of C(Hβ)=0.30. In Figure 1 we present part of the spectrum showing all the emission lines of multiplet 1 of O II. The absence of blends and the high S/N are evident from this figure.

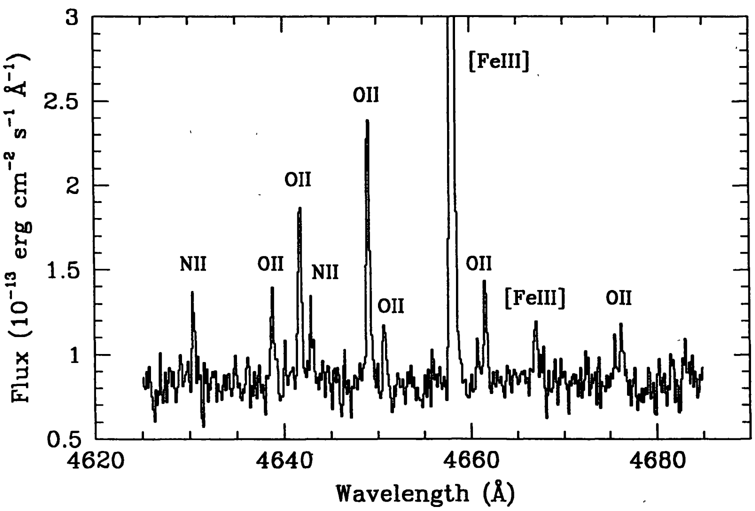

Fig. 1. Part of the echelle spectrum showing all the individual emission lines of multiplet 1 of O II.

We have compared our data with those from previous works by Kaler, Aller, & Bowen (1965) and Osterbrock et al. (1992). The photographic data of Kaler et al. clearly shows a systematic trend in the sense that the ratio of the weaker lines to the stronger ones is higher than in our data. The overestimation of the intensity of weak lines in photographic data has been known for a long time (e.g., Miller 1971). In contrast, the comparison with the data of Osterbrock et al. does not show such trend, as expected, since both studies are based on CCD observations. Several line intensities given by Osterbrock et al. appear to be slightly higher than ours, these differences could be produced by line blending due to the lower spectral resolution of their data.

We have derived the physical conditions from forbidden line analysis and they are consistent with those obtained in previous works for the same zone (e.g., Peimbert & Torres–Peimbert 1977).

From the O II recombination lines of the multiplets 3p $^4D^o$–3s ^4P (M1), 3p $^4P^o$–3s ^4P (M2) and 3d ^4F–3p $^4D^o$ (M10), we have calculated the O^{++}/H^+ values using the effective recombination coefficients, α_{eff}, presented by Storey (1994) and Liu et al. (1995), and corrected for stellar absorption following the prescriptions given by Peimbert et al. (1993). In Table 1 we show the values of O^{++}/H^+ obtained, for cases A and B, for the sum of all the lines observed of each multiplet. The derived values are very consistent, with a dispersion factor less than 2, although we find that the results obtained from M2 are slightly different depending on the assumed case. Considering case B for all the multiplets we obtain an average $O^{++}/H^+ = 39 \pm 5 \times 10^{-5}$ (12+log O^{++}/H^+= 8.59±0.06), a value 40% larger than that obtained using forbidden lines.

TABLE 1

O^{++}/H^+ ABUNDANCE

Multiplet	Case A	Case B
M1	$39 \pm 7 \times 10^{-5}$	$38 \pm 7 \times 10^{-5}$
M2	$57 \pm 14 \times 10^{-5}$	$41 \pm 8 \times 10^{-5}$
M10	$39 \pm 9 \times 10^{-5}$	$39 \pm 9 \times 10^{-5}$
<M>	$41 \pm 6 \times 10^{-5}$	$39 \pm 5 \times 10^{-5}$

TABLE 2

C^{++}/H^+ ABUNDANCE

α_{eff}	Multiplet	Case A	Case B
Péquignot et al. (1991)	M2	$75 \pm 15 \times 10^{-5}$	$17 \pm 4 \times 10^{-5}$
"	M6	$26 \pm 5 \times 10^{-5}$	$26 \pm 5 \times 10^{-5}$
Pengelly (1963)	"	$32 \pm 6 \times 10^{-5}$	$32 \pm 6 \times 10^{-5}$

The C^{++}/H^+ value was derived using the C II $\lambda\lambda$4267 (M6) and 6578 (M2) lines and the results are presented in Table 2. For the C II λ4267 emission line we used the α_{eff} calculated by Pengelly (1963) and Péquignot, Petitjean, & Boisson. (1991) obtaining differences in C^{++}/H^+ on the order of 20%. On the other hand, the C II λ6578 line appears to be inappropriate for abundance derivation since it is quite sensitive to the assumed case. From the C II λ4267 emission line, we obtain a C^{++}/H^+ value a factor of 3 higher than that derived by Walter et al. (1992) for the same zone, based on the UV C III] $\lambda\lambda$1906+1909 lines.

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, associated with the observed region. This parameter gives a value of 0.020 in the case of O^{++}/H^+ and between 0.034 and 0.040 for C^{++}/H^+ depending on the set of α_{eff}s used (see Table 3). An average of $t^2 = 0.025 \pm 0.015$ could be a nominal representative value for the observed zone. This is a moderate value, somewhat low compared with other estimates obtained in previous works (e.g., Peimbert & Torres–Peimbert 1977; Walter et al. 1992; Peimbert et al. 1993) and definitely lower when compared with recent estimates for PNe made by several authors, who find values of about 0.05 and 0.08 (Liu et al. 1995; Kingsburgh & López 1995). The t^2 differences could be due to the smaller area observed. If

TABLE 3

t^2 PARAMETER

	Forbidden lines	Recombination lines	t^2
12+log(O^{++}/H^+)	8.43±0.07	8.59±0.08	0.020±0.010
12+log(C^{++}/H^+)	7.97±0.15[a]	8.41±0.08[b]	0.034±0.008
		8.51±0.08[c]	0.040±0.008

[a]Derived using C III] λλ1906+1909 (Walter et al.1992).
[b]α_{eff} from Péquignot et al. (1991)
[c]α_{eff} from Pengelly (1963)

these differences are real they could place restrictions on the spatial size of the possible sources of temperature fluctuations, providing further clues to understand the nature of such phenomena. Observations of different parts of the nebula and of other bright H II regions could shed some light on this problem.

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