

CARBON IN ORION¹

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ABSTRACT

The carbon abundance in the Orion nebula has been redetermined from a detailed study of UV spectra in the IUE archives. Temperature and electron density gradients were derived for the inner 5 arc minutes of the nebula using new and existing observational data. These temperatures and densities were used to calculate the carbon abundance for 19 positions largely north or west of the Trapezium. The new carbon abundance is found to be $\log(C/H) + 12 = 7.83 [+0.13, -0.20]$. This is 0.5–0.7 dex lower than previous studies found. New atomic parameters, a newer UV extinction curve, and higher temperatures account for these differences from previous studies. C/H and C/O are found to be constant across the face of the nebula. The influence of temperature fluctuations on abundances was investigated.

Key words: carbon abundance—elemental abundances—H II regions—Orion nebula—spectrophotometry: UV and optical

1. Introduction

Previous studies of the carbon abundance in the Orion nebula based on IUE spectra include the works by Torres-Peimbert, Peimbert & Daltabuit 1980 and Perinotto & Patriarchi 1980. They both found M 42 to be underabundant in carbon with respect to the Sun by 0.2 dex. These works were based on only a few positions in the nebula and as such did not allow a detailed examination of the abundance issue. This study makes use of the large archival database of IUE spectra for Orion and combines them with new and existing optical data to form the most comprehensive study of abundance and ionization structure in Orion. This article will deal with the carbon abundance in the nebula, which is part of a larger study by Walter, Dufour & Hester 1991 that examines the dust and CNO ionization structure of the inner 5 arc minutes of M 42.

2. Observations

Over 300 IUE spectra of Orion exist in the archives. Reprocessing of approximately 150 was requested and

42 of those were chosen for studying the carbon issue. This meant that 21 pairs of spectra at 19 unique positions in the nebula had total UV coverage from 1300 Å–3000 Å.

New ground-based spectra of nine positions were obtained using the 0.9-m telescope with IRS at KPNO and the 1.5-m telescope with SIT Vidicon at CTIO. Spectrophotometry was also gathered from ten separate articles in the literature between 1969 and 1990.

The most significant addition to the database was a set of CCD images obtained in 1987 by Dufour and Hester on the 60-inch (1.5-m) telescope at Mount Palomar. These images are 16 arc minutes square with a resolution of 1.2 arc seconds per pixel and were taken at six emission-line and three continuum bands. The CCD imagery allowed one-to-one mapping of IUE positions with optical positions. Past studies had to rely on optical positions which were oftentimes nearby, but not at the same location as the IUE positions. The 19 positions used in this study were largely confined to the quadrant north and west of the Trapezium where the surface brightness is relatively smooth. Localized features such as the bar were avoided.

3. Abundances

The abundances were calculated using the five-level program of De Robertis, Dufour & Hunt 1987. The atomic parameters used were newer than the ones used in the earlier abundance studies. Electron temperatures and densities were required in order to carry out these calculations. There has been some question about the correct temperatures and densities to use for Orion. Bohuski, Dufour & Osterbrock 1974 found an [O III] temperature gradient in the nebula, while McCall 1979

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claimed no such gradient existed. To resolve this question, new data plus those which were available in the literature were used to derive relations for temperature and density as a function of distance projected on the sky from the Trapezium. It was found that the [O III] temperature increased with increasing distance from the Trapezium, while the [N II] temperature decreased. The electron density, derived from the [S II] lines, also decreased with increasing distance. The precise form of the functional fit of the temperature and density gradients will be published in an upcoming paper.

The standard practice was followed of using the [N II] temperature for the low-ionization species C^+ and the [O III] temperature was used for C^{++} . The results are shown in Figure 1. As a check on the significance of using a temperature gradient, C abundance calculations were carried out for an isothermal nebula. The results were virtually identical to those in Figure 1 for the overall abundance of C. The presence of a temperature gradient is not as important as is the zero point of the temperature scale.

There are two things to notice about the values of C/H in Figure 1. First, the C/H abundance across the nebula is constant, at least within the range of the error bars. It has been suggested that there should be a decrease in carbon in the gaseous phase as one moves away from the Trapezium. Such a decrease is expected because a number of observers have found a paucity of dust in the inner 3 arc minutes of the nebula. If the grains in that region were

destroyed then the carbon locked up in the grains would have been released and the abundance of gaseous phase carbon would be higher closer to the Trapezium. No decrease is apparent in Figure 1. Furthermore, the value of C/O was found to be constant across the face of the nebula. The results of those calculations will be presented in an upcoming paper.

A second thing to notice is that the abundance values shown here are lower than those from past studies. Table 1 summarizes the results of previous ultraviolet studies of carbon in Orion compared to this study. The mean C abundance determined here is $\log(C/H) = 7.83 [+0.13, -0.20]$, approximately 0.5–0.7 dex lower than that found previously.

4. Past Studies

There are three major reasons for the differences in the abundances derived by this study compared to previous studies.

1. Newer atomic parameters were used in calculating abundances in this work.
2. A newer and more accurate extinction curve for Orion in the UV is now available.
3. Higher temperatures were used in this study.

Table 2 demonstrates the relative importance of each of these factors in lowering the carbon abundance. The third column lists the value of carbon quoted in the original works by the authors. The fourth column shows how this quantity changes if all the original data from the authors

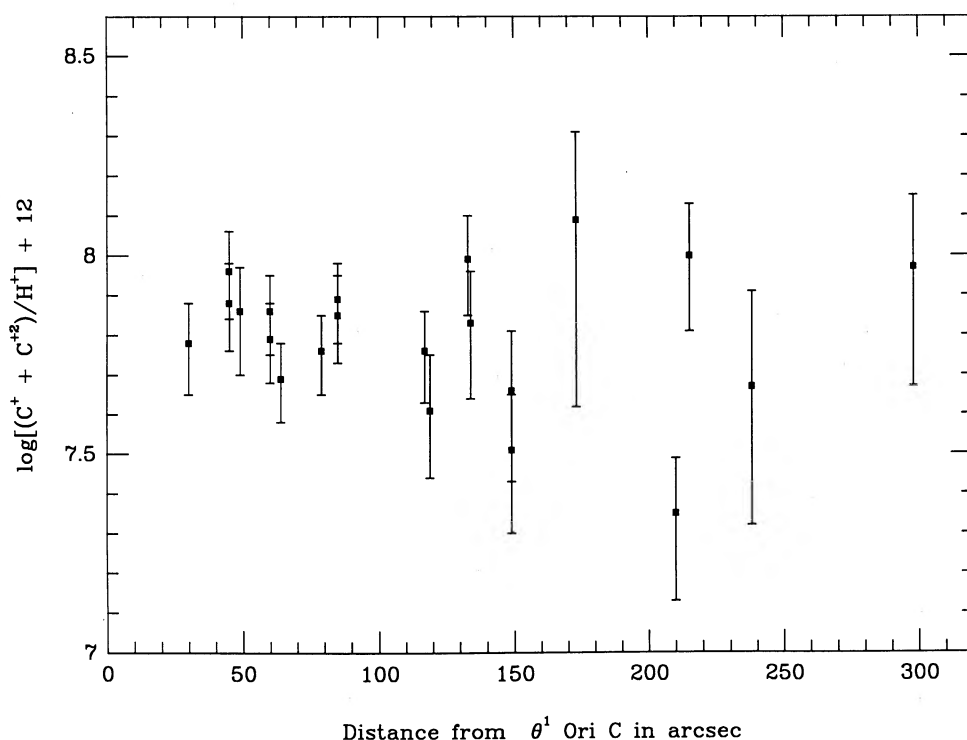


FIG. 1—The total C/H abundance in the Orion nebula as determined from UV lines in IUE spectra as a function of distance from θ^1 Orionis C. Abundances were calculated as described in the text assuming a nonisothermal nebula.

TABLE 1

Carbon Abundance in Orion

Reference ^a	log(C/H) + 12	# of IUE Spectra
This study	7.83	42
PP	8.39	4
TPPD	8.35	5
TPPD	8.52	optical
Solar	8.67	

^a PP – Perinotto & Patriarchi 1980

TPPD – Torres-Peimbert, Peimbert & Daltabuit 1980

Solar – Lambert 1978

TABLE 2

Revisions to Past Orion Carbon Abundances

Reference	Position	Original	New Atomic	New Extinction	Higher T
PP	1	8.37	8.26	8.14	7.84
PP	2	8.40	8.31	8.09	7.83
TPPD	1uv	8.35	8.25	8.08	7.79
TPPD	2uv	8.35	8.26	8.09	7.88
TPPD	3uv	8.35	8.31	8.22	8.14
Mean		8.36	8.28	8.12	7.90

See text for explanation of column headings
References are the same as in Table 1

(temperatures, fluxes, extinction, etc.) are used except that the newer atomic parameters in the five-level atom program are applied. The fifth column shows the cumulative effect of using new atomic parameters and a newer extinction relation. The previous works used the Orion UV extinction curve of Bless & Savage 1972 and Savage 1975. That relationship was derived from OAO-2 data. One year after the publication of the previous carbon studies, Bohlin & Savage 1981 published an extinction curve for Orion in the UV based on IUE data. The OAO-2 curve overcorrected for reddening in the UV. The newer Bohlin and Savage curve was applied to the earlier works with the result that the C abundances were lowered even further. Finally, the sixth column shows the effect of applying new atomic parameters, newer extinction, and higher temperatures. Applying all three of these corrections to the previous C values brings them within the range of the standard deviation of the mean of this study.

5. Fluctuations

Studies by Peimbert 1967, Rubin 1969, and Peimbert & Costero 1969 have shown that it may be necessary to correct abundance calculations for localized fluctuations in temperature and density in an H II region. The effect

TABLE 3

Fluctuation Effects on Carbon Abundance

t^2	This Study	TPPD
0.000	7.83	8.35
0.020	8.06	8.57
0.035	8.28	8.79

See text for explanation of column headings
References are the same as in Table 1

of these fluctuations was examined here and the results are shown in Table 3. The procedure for making these corrections is described by Peimbert & Costero 1969 and in Peimbert & Torres-Peimbert 1977. The fluctuations are characterized by an rms temperature fluctuation given as t^2 . The larger the value of t^2 the greater the variation in localized temperatures and the greater the correction which must be made to the temperatures input into the abundance calculations. A value of $t^2 = 0.0$ means that the temperatures from the observation of forbidden lines were not corrected but were used directly, as was done in Section 3 of this paper.

A value of $t^2 = 0.035$ was derived for Orion in the Peimbert & Torres-Peimbert paper. It can be seen that applying it here raises the carbon abundance by 0.2–0.4 dex. Nonetheless, this does not detract from the fact that the carbon abundance in this study is about 0.5 dex lower than earlier studies. As Table 3 shows, if a nonzero t^2 value is applied to the earlier works, their carbon abundances would be higher than the base value originally calculated. When examining the various studies, one must compare the abundances derived using the same value for t^2 .

Calculations showed that even higher values for t^2 yielded values for C/H and C/O similar to the values for the Sun. If $t^2 = 0.05$ – 0.07 then the Orion abundances for C/H and C/O are equal to the solar values. It is interesting to note that Peimbert & Costero 1969 first suggested t^2 values in this range for the Orion nebula.

6. Conclusions

1. The C/H and C/O abundances are constant across the face of the nebula.

2. Based on temperatures from [O III] and [N II], the mean carbon abundance should be lowered by 0.2–0.3 dex due to newer atomic parameters and a more accurate UV extinction curve. An additional lowering of 0.2–0.3 dex may be in order if higher temperatures in Orion are to be believed. This study finds a value for the abundance of $\log(\text{C/H}) + 12 = 7.83 [+0.13, -0.20]$.

3. Temperature fluctuations can raise the carbon

abundance by 0.2–0.5 dex, but the lowering of carbon compared to the past values with the same correction for fluctuations is still necessary. If C and O in Orion are required to be similar to the solar values, then temperature fluctuations of $t^2 \approx 0.5$ –0.7 are required to exist.

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