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THE OPTICAL SPECTRUM OF THE NEBULA YM 29

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ABSTRACT

New spectrograms of the nebula YM 29 lend some support to the identification of this object as a low-excitation planetary nebula. The abundances of oxygen, nitrogen, and probably sulfur in this nebula are close to the mean values for these elements in planetary nebulae.

Subject headings: abundances, nebular — nebulae, individual — planetary nebulae

I. INTRODUCTION

The nebula YM 29 was classified by Johnson and Rubin (1971) as a peculiar planetary nebula. Their classification was based on radiofrequency data and on three spectrograms of the nebula, taken in the blue. A few more spectrograms of the nebula were recently taken at the Wise Observatory, mainly in the red spectral region. These provide new data on the excitation conditions, the electron density, the electron temperature, and the chemical composition of the nebula. The new data add some support to the identification of YM 29 as a low-excitation planetary nebula with an abundance of heavy elements close to the mean for these objects.

II. OBSERVATIONS

Six spectrograms of YM 29 were taken by the author and by Dr. Susan Wyckoff and Dr. Peter Wehinger in 1973 and 1974. All were taken with an image-tube spectrograph attached to the 1-m reflecting telescope of the Wise Observatory, with a dispersion of 76 Å mm^{-1} in the second-order blue. A combination of an S25 photocathode and a 103aD emulsion was used in all the exposures, three with a Wratten W-4 filter, one with a Schott BG 38 filter, and two without a filter. The slit of the spectrograph was oriented either in the east–west or in the north–south direction, through the bright knot in the north eastern end of the nebula. Atmospheric extinction and the instrumental response function were determined by frequent recordings of the spectra of stars from Hayes's (1970) list of photometric standard stars. All plates were traced several times with a Joyce-Loebl microdensitometer, and the corresponding characteristic curves were extracted from calibration plates, taken with a spot-sensitometer.

In table 1 we give a few details of the individual plates taken in this study. Table 2 presents the intensities outside the Earth's atmosphere of the emission lines adopted from the six plates for the bright knot in YM 29. The intensities of the lines in the red spectral region are given relative to an intensity of 100 for Hα. The intensities in the blue region are relative to $I(3727) = 100$.

The main source of error in the line intensities is

TABLE 1

DETAILS OF THE SPECTROGRAMS

Plate No.	Date	Filter	Slit Orientation	Exposure Time (Min)
305........	1973 Mar. 31–Apr. 1	...	N–S	90
543........	1973 Nov. 28–29	...	N–S	60
686........	1974 Feb. 14–15	W-4	N–S	77
688........	1974 Feb. 15–16	W-4	E–W	90
697........	1974 Mar. 26–27	W-4	N–S	75
707........	1974 Mar. 27–28	BG 38	N–S	100

TABLE 2

OBSERVED RELATIVE LINE INTENSITIES OUTSIDE THE EARTH'S ATMOSPHERE

BLUE				RED					
[O II] 3727	Hβ 4861	[O III] 4959	[O III] 5007	[O III] 5007	[N II] 6548	Hα 6563	[N II] 6584	[S II] 6717	[S II] 6730
100......	17	14	31	35	96	100	242	53	42

the atmospheric extinction, which was unstable during some of the observing runs. Thus the probable error is larger for lines far away from the reference line in each spectral region. From the scattering of the measurements of the standard stars around the adopted extinction curve for each night, we can estimate that the error is no larger than 30 percent; and in the lines used in the intensity ratios that we shall mainly consider, it is about 15 percent or less.

The intensity of the nebular lines in other regions of YM 29 could not be reliably determined from our plates, because of the lower surface brightness of the other regions. There is no other single part of the nebula for which we have on our plates data for sufficiently reducing the statistical error in the intensities. The following analysis and discussion of the observations is therefore limited to the bright knot at the northeast end of YM 29.

In addition to the lines listed in table 2, the spectrograms of YM 29 show also nebular emission in the [O I] $\lambda6300$ line. This is evident from the nonuniformity in the intensity of the $\lambda6300$ line in the spectrum, along the segment of the slit that was exposed to nebular radiation (see fig. 1 [pl. 4]). The distribution of the light intensity along the $\lambda6300$ line clearly indicates a superposition of nebular emission on the nightsky line. No attempt was, however, made to estimate the intensity of the nebular [O I] line.

III. DISCUSSION

In order to determine the interstellar reddening between the Sun and YM 29 from the observed line intensities, we can compare the observed Balmer decrement $D = I(\text{H}\alpha)/I(\text{H}\beta)$ to the theoretical value. The two hydrogen lines are in the two different spectral regions in our spectrograms. The [O III] $\lambda5007$ line, however, appears on both the red and the blue plates, and through it we can determine an observed value of $D = 5.2$. This value is very uncertain because the possible relative error in it is the sum of the largest possible errors in each region of the spectrum. Fortunately, most of the line ratios we are concerned with here are only weakly sensitive to interstellar reddening.

The theoretical Balmer decrement for a collisionally excited plasma is given by Parker (1964*a*). For electron temperature $T_e < 2 \times 10^4\,°$, the theoretical value is about equal or even greater than our observed D, implying no interstellar reddening in the direction of YM 29. We shall later show that it is very unlikely that YM 29 is collisionally excited.

For a radiatively excited nebula under case B of Baker and Menzel (1938), the observed value of D compared with the theoretical value as computed by Brocklehurst (1971) indicates a reddening constant $c = 0.76, 0.72$, and 0.66 for $T_e = 2 \times 10^4\,°, 1 \times 10^4\,°$, and $5 \times 10^3\,°$ K. We adopt $c = 0.70$ and obtain the line intensity ratios presented in table 3.

Electron density. The electron density of the region from which the sulfur lines are emitted can be determined from the observed line ratio $P = I(6730)/I(6717)$. The table given by Saraph and Seaton (1970) and the value $P = 0.8$ in YM 29 give $N_e \simeq 350(10^{-4}T_e)^{1/2}$ when the correction recommended by the authors is applied to the table, and $N_e \simeq 630(10^{-4}T_e)^{1/2}$ without the correction. We shall later see that the most probable electron temperature T_e for the northeastern part of YM 29 is about 8000° so that $N_e \simeq 300\ \text{cm}^{-3}$. This result is in agreement with the electron density range derived by Johnson and Rubin (1971) from the [O II] lines.

The most outstanding feature of the spectrum of YM 29 is the value of the line ratio $R = I(\text{H}\alpha)/I(6584, 6548) = 0.3$. This value is unusual for galactic H II regions (Burbidge and Burbidge 1962) in most of which $R > 1$, although it is not uncommon in planetary nebulae. In YM 29 it removes the apparent underluminosity of the nebula at 6 cm (Johnson and Rubin 1971), as it reveals that the red flux from this nebula is due mainly to the [N II] lines and not to Hα.

The problem of the value of R in gaseous nebulae was discussed at length by Burbidge, Gould, and Pottasch (1963), Parker (1964*b*), Peimbert (1968), and others. The discussion by Parker is probably not applicable here, because it is very unlikely that YM 29 is collisionally ionized. When we use Parker's expressions for line intensities in a collisionally excited nebula and our observed line ratios R, V, and W, we obtain an excessive overabundance of oxygen at low temperatures. Even at $T_e = 20{,}000°$, the abundance of oxygen relative to hydrogen is still at least three orders of magnitude higher than what is considered normal in gaseous nebulae, B stars, or the Sun. At higher temperatures, the required abundance of oxygen decreases rapidly, but then the abundance of nitrogen has to be increased. At $T_e = 30{,}000°$, the required abundance of nitrogen is two orders of magnitude larger than any normal abundance of this element.

We therefore turn now to expressions relating our line intensity ratios to relative abundances of ions in a radiatively excited nebula. First we note that the presence of a nebular [O I] emission indicates the existence of an H I region on the line of sight to the nebula. This would mean that the optical knot is

TABLE 3

LINE INTENSITY RATIOS IN YM 29, CORRECTED FOR INTERSTELLAR REDDENING

R 6563/(6584 + 6548)	Q 3727/5007	P 6730/6717	V 6563/5007	W 4861/3727	U 6563/(6717 + 6730)
0.3	5.8	0.8	1.7	0.1	1.14

ionization bounded, at least in some directions. Our abundance analysis is applied to the H II region, in which, we assume, no O^0 exists. We also assume, on the basis of the similarity in the ionization potentials, that in the H II region, all the nitrogen atoms are ionized at least once.

The concentrations of the ions O^+, O^{++}, and N^+ relative to H^+, as functions of the electron temperature can be derived from the line intensity ratios R, V, W, and Q, and expressions (14), (15), and (16) in Peimbert (1968). The total abundance of oxygen atoms in the nebula can then be determined, assuming that no ionization higher than O^{++} exists in the observed region. The abundance of nitrogen atoms is obtained approximately by multiplying the $N(N^+)/N(H^+)$ ratio with the ionization correction factor of the oxygen ions (Peimbert 1968).

The ionized sulfur abundance ratio $N(S^+)/N(H^+)$ can be determined from expressions (7) and (31) in Peimbert and Costero (1969) and our observed value of U. The total relative abundance of sulfur in the H II region is

$$\frac{N(S)}{N(H)} = \frac{N(S^+) + N(S^{++}) + N(S^{+++})}{N(S^+)} \frac{N(S^+)}{N(H^+)} = a_s \frac{N(S^+)}{N(H^+)} . \qquad (1)$$

The ionization potential of S^+ is almost equal to that of He^0; therefore,

$$a_s = \frac{N(He^0) + N(He^+)}{N(He^0)} = a_{He} , \qquad (2)$$

but

$$a_{He} = \frac{N(He^0) + N(He^+)}{N(H^+)} \frac{N(H^+)}{N(He^0)} = \rho(He) \frac{N(H^+)}{N(He^0)} , \qquad (3)$$

where ρ(He) is the total concentration of helium in the nebula. The absence of the λ5876 line of He I from our spectrograms enables us to put an upper limit Y to the line intensity ratio $I(5876)/I(H\alpha)$. From the value of Y and from table 4 in Leibowitz (1973) we obtain an upper limit to $B = N(He^+)/N(H^+)$ as a function of T_e. From expression (3) we have

$$a_{He} = \frac{\rho(He)}{\rho(He) - B} . \qquad (4)$$

Using expressions (1), (2), and (4), we can now put an upper limit to the abundance of sulfur as a function of T_e and the abundance of helium in the nebula. The value of ρ(He) in planetary nebulae is typically between 0.1 and 0.15 (Peimbert and Torres-Peimbert 1971). The lowest upper limit for $\rho(S) = N(S)/N(H)$ will be obtained when ρ(He) takes the largest value in its range of variation and when Y is the lowest value permitted by our spectrograms. In deriving the upper limit for ρ(S) we therefore adopt $\rho(He) = 0.15$ and $Y = 0.06$.

The abundances of the various ions and atoms and the upper limit to the abundance of sulfur, as derived from the observed line ratios in YM 29, are presented in table 4.

From the dependence of $N(N)/N(H)$ on T_e we find that nitrogen assumes in YM 29 the mean value for planetary nebulae, as given by Aller and Liller (1968), at $T_e = 7500°$ K. Oxygen takes the mean value at $T_e = 8500°$. At both temperatures the upper limit for the abundance of sulfur in YM 29 lies above the mean abundance of this element in planetary nebulae. If we take as the mean abundances of O, N, and S in planetary nebulae the values given by Kaplan and Pikel'ner (1970), we obtain from nitrogen $T_e = 8000°$ and from oxygen $T_e = 9000°$. The mean abundance of sulfur in planetary nebulae is not inconsistent with the upper limit for this atom in YM 29 at these temperatures.

Our expectation for a single value of T_e in the abundance analysis is partially justified by models of planetary nebulae (Flower 1969), in which T_e varies only between 7500° and 11,000° K in the O^+ and O^{++} zone in the nebula. It is further justified by the fact that the analysis is applied to the bright knot in YM 29 and not to the nebula in its entirety. Considering the possible observational errors in the line intensities and particularly the large uncertainty in the interstellar reddening, we can regard the results of our data analysis as internally self-consistent. We therefore believe that they do represent the electron temperature and, within a 50 percent accuracy, the true abundance of the elements in YM 29. For a comparison, if we express our abundances in YM 29 in terms of the solar abundances, we find for nitrogen $T_e = 13,000°$ and for oxygen $T_e = 8000°$.

The appearance of the [O III] N_1 and N_2 lines in the spectrum of YM 29 removes this nebula from Aller's (1956) excitation class 1 (Johnson and Rubin 1971). The line ratio $(N_1 + N_2)/3727$ classifies YM 29 as an excitation class 3 nebula. In fact we find that except for the line ratio P, the spectrum of YM 29 is very similar to that of IC 418 (O'Dell 1963), the prototype class 3 planetary nebula. The nebula IC 418 has also

TABLE 4

ABUNDANCES OF IONS IN THE NEBULA YM 29

Ratio	T_e(° K) 5×10^3	1×10^4	2×10^4
$N(O^+)/N(H^+)$.....	2.3×10^{-2}	3.8×10^{-4}	4.1×10^{-5}
$N(O^{++})/N(H^+)$....	1.4×10^{-3}	6.1×10^{-5}	1.1×10^{-5}
$N(O)/N(H)$........	2.4×10^{-2}	4.4×10^{-4}	5.2×10^{-5}
$N(N^+)/N(H^+)$.....	1.3×10^{-3}	1.1×10^{-4}	2.9×10^{-5}
$N(N)/N(H)$........	1.4×10^{-3}	1.3×10^{-4}	3.7×10^{-5}
$N(S^+)/N(H^+)$......	1.6×10^{-4}	1.4×10^{-5}	3.6×10^{-6}
$N(S)/N(H)$........	7.9×10^{-4}	8.8×10^{-5}	5.2×10^{-5}

NOTE.—The values for $N(S)/N(H)$ are derived under the assumption of $N(He)/N(H) = 0.15$ and are upper limits.

a small value of $R = 1.2$, although not as small as in YM 29. The difference may be due to a difference in the abundance of heavy elements in the two nebulae. The differences between the two nebulae in their ratios of the [O II] and [O III] lines to Hα and Hβ also point to a difference in the abundances in the same direction—namely, that IC 418 is more deficient in heavy elements.

We conclude that YM 29 is a planetary nebula of excitation class 3, with normal thermal radio emission. The electron temperature in the bright knot in the nebula is about 8000° K, and the electron density is about 300 cm^{-3}. The chemical composition of this concentration in the nebula is close to the average for planetary nebulae. The nebula is still somewhat peculiar, being a low-excitation nebula in spite of an apparent old age, as indicated by the large angular size, the low surface brightness, and the low density. The low excitation level may be partly due to the fact that our observations were concentrated on the bright knot which may constitute a particular dense and cool condensation in the nebula. It may also be partly due to the nature of the exciting star, which may be a relatively cool star for a nucleus of a planetary nebula.

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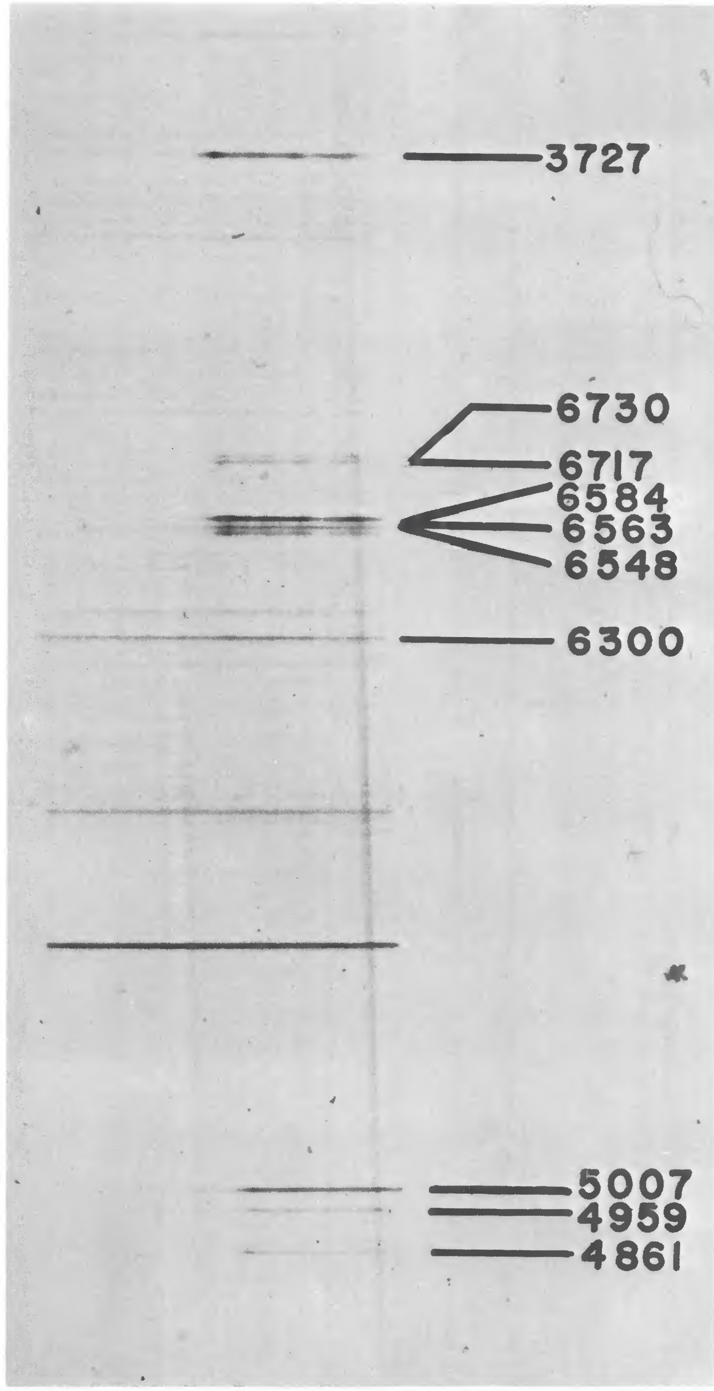

FIG. 1.—Plate 543, unwidened spectrogram of YM 29, taken with an ITT F4089 image tube with an S25 photocathode on a 103aD plate with no filter. The λ3727 line is from the second-order blue while the other emission lines are from the first-order red.

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