THE ASTROPHYSICAL JOURNAL, 278:195–200, 1984 March 1

THE O VI NUCLEUS OF THE PLANETARY NEBULA M3-30

JAMES B. KALER AND RICHARD A. SHAW
Astronomy Department, University of Illinois
Received 1983 May 16; accepted 1983 August 11

ABSTRACT

The central star of the planetary nebula M3-30 exhibits an unusually powerful blended O VI doublet at λ3820, comparable to those found in the stellar spectra of NGC 5189, 6905, and 7026. The star also displays strong C IV at λ4658, probably blended with stellar He II λ4686. The equivalent width $[F(\text{O VI})/F(\lambda 3820)d\lambda]$ of the O VI doublet is 290 Å, and that of the λ4658–λ4686 blend is 100 Å. The velocity widths (FWHM) of the individual components of the O VI blend and of the deconvolved C IV λ4658 are similar, about 2500 km s^{-1}.

The star is very hot, with a He II Zanstra temperature of 126,000 K. Since nebular helium is nearly fully doubly ionized, the nebula may be optically thin in the He^+ Lyman continuum, and the true effective temperature may be higher yet, although the precision of the measurement is limited by a poor determination of the nebular Hβ flux. At this temperature, and at an estimated distance of 4200 pc, the stellar luminosity is $1.4 \times 10^3\ L_\odot$. The fraction radiated in the O VI lines in 3.8×10^{-4}, less if the temperature is higher. For comparison, we make estimates of these same quantities for other O VI stars from data found in the literature. Except for the generally high luminosities and temperatures of the stars, no correlations can be found between O VI strength and position on the log L–log T plane, which may reflect the generally poor state of the available data.

Subject headings: nebulae: individual — nebulae: planetary

I. THE O VI STARS

The central stars of planetary nebulae exhibit a wide variety of spectral types, as might be expected given their broad distribution in temperature and luminosity. Some show nearly featureless continuous spectra; others exhibit only absorption lines, while still others have emission spectra, sometimes with absorption features, sometimes not; see Aller (1968) for a general review. The still definitive work on the spectroscopic classification of the emission-line nuclei was provided by Smith and Aller (1969), who divided them into five groups, based upon their resemblance to stars of Population I: Wolf-Rayet, O VI, Of, Ofp, and Wolf-Rayet–Of. Of these, the O VI stars may be the most bizarre. The characteristic feature is the O VI doublet at λ3811 Å and λ3834 Å; the λ5292 blended doublet can also be fairly prominent (Aller 1977).

Within the O VI group the stars exhibit a wide variety of line strengths, from quite weak, as in the nucleus of NGC 246 (Aller 1948; Heap 1975), in which the components of the λ3811–λ3834 doublet are narrow and completely separated, to strengths and widths so great that the blended doublet dominates the entire nebular-stellar spectrum, as in NGC 6905, NGC 7026, and NGC 5189 (see Smith and Aller 1969; Blanco *et al.* 1968; Aller 1968). The visual spectrum of NGC 2452 presented by Aller (1977) shows that its central star may also be part of the group, but no ultraviolet observations are available. Heap (1982) gives a general review of characteristics. The strong O VI stars are quite rare and are almost exclusively planetary nuclei (Smith and Aller 1969). One exception is a peculiar star in Sagittarius with which no known planetary nebula is associated (Blanco, Kunkel, and Hiltner 1968; Freeman, Rodgers, and Lyngå 1968; Johnson 1975).

It is thus with some significance that we announce the discovery of another star with powerful O VI emission, the nucleus of the planetary nebula M3-30 (17–4°1 in the catalog of Perek and Kohoutek 1967). Of perhaps greater moment, we have made quantitative measurements of the strength of the line relative to the luminosity of the star, information that is needed to determine ultimately how the O VI nuclei fit into the general scheme of planetary evolution.

In the next section we discuss the observations, present line strengths for both the nebula and the star, and use the data to determine stellar and nebula parameters. In § III we make similar quantitative estimates of the line strengths in the spectra of other O VI stars from data found in the literature, and briefly examine correlations with other parameters, as well as the lack thereof.

II. OBSERVATION AND ANALYSIS

a) The Data

We observed M3-30 on 1982 April 25 (UT) with the University of Arizona blue reticon system at the Cassegrain focus of the 2.3 m telescope at Kitt Peak, in the usual beam-switching mode, with a total integration time of 4 minutes. The aperture was centered on the nucleus, visible in the acquisition television system, which resulted in a combined spectrum of the nebula and star. M3-30 was included as an ordinary program object in a survey of planetaries, and discovery of the unusual nature of the star was a surprise. We reduced the raw data with the University of Arizona reduction programs, which include automatic sky subtraction, and correct the data to outside the atmosphere in the usual way with the aid of standard star observations taken on the same night.

We show the resulting reduced spectrum, with important lines marked, in Figure 1. Note in particular the great strength of λ3820 (the mean wavelength of the combined doublet) of

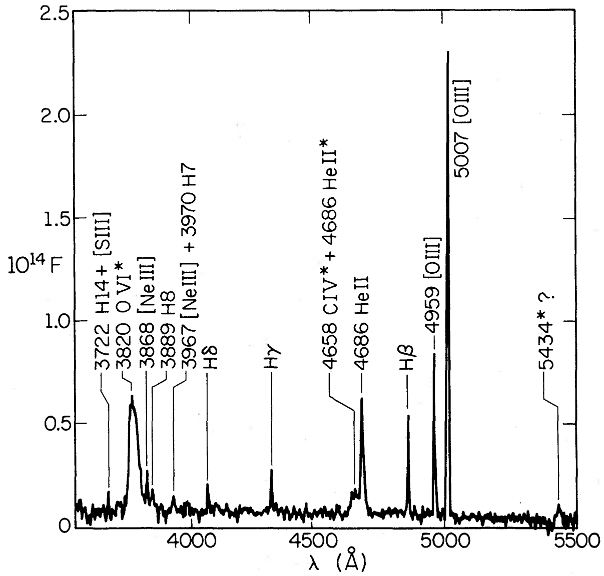

FIG. 1.—The spectrum of M3-30 and its central star. An asterisk denotes a stellar line. The feature at λ5434 is probably spurious.

O VI, which dominates all other features. Also note stellar C IV λ4658 in emission, which from the asymmetry of the profile underneath nebular λ4686, seems to be blended with stellar He II λ4686, plus the usual array of other nebular lines of [O III], H, and [Ne III]. The excitation of the spectrum is very high, with nebular He II λ4686 (superposed on the stellar feature) comparable in strength to Hβ, implying a high central star temperature and/or luminosity.

We integrated the nebular line strengths at Illinois with a Gaussian-fitting routine, taking into account the underlying broad stellar emissions at λ3820 and λ4658 in order to derive measurements of the pure nebular spectrum. We present the observed relative line fluxes (F) in column (3) of Table 1a, on the usual scale of $F(\text{H}\beta) = 100$. The errors are only approximate and are derived from the measured widths of the fitted Gaussians relative to the mean. All nebular line profiles should have the same intrinsic width at the dispersion used, and the variation in the width should be some measure of random error.

We determined the extinction constant [logarithmic extinction at H(β)], c, from the Balmer decrement (Hβ, Hγ, and Hδ), the theoretical predictions of Brocklehurst (1971), and the Whitford (1958) extinction curve. The agreement between the values for extinction derived separately from the two ratios $F(\text{H}\gamma)/F(\text{H}\beta)$ (0.60 ± 0.26) and $F(\text{H}\delta)/F(\text{H}\beta)$ (0.0 ± 0.2) is poor. Some of the problem may come from λ4103 and λ4097 of N III blended with Hδ. But inspection of Aller and Czyzak's (1969) photometry of high-excitation planetaries shows that the N III lines should not sum to greater than 1%–2% of Hβ, and thus even at the extreme, $c(\text{H}\delta) \approx 0.1$. The difference is probably due to observational error, and since the signal-to-noise ratio is clearly better for Hγ, we give that line double weight to derive $c = 0.4$ with an adopted error

TABLE 1

OBSERVED AND CORRECTED LINE FLUXES

A. NEBULAR

λ (1)	ID (2)	F (3)	f_λ (4)	I[a] (5)
3723	H14, [S III]	17 ± 3	0.30	22 ± 5
3868	[Ne III]	24 ± 5	0.26	30 ± 6
3889	H8	20 ± 7	0.25	25 ± 9
3967	[Ne III]	16 ± 5	0.23	20 ± 7
3970	H7	...	...	...
4101	Hδ	27 ± 3	0.195	32 ± 5
4340	Hγ	39 ± 3	0.135	44 ± 4
4363	[O III]	4.6 ± 2.0	0.13	5 ± 2
4686	He II	112 ± 27	0.45	117 ± 28
4861	Hβ	100	0.00	100
4959	[O III]	150 ± 18	−0.015	148 ± 13
5007	[O III]	426 ± 53	−0.035	412 ± 40

$S(\text{H}\beta)$ (central hole) $= 2.0 \pm 0.2 \times 10^{-15}$ ergs cm^{-2} s^{-1} arcsec^{-2}

B. STELLAR

λ (1)	ID (2)	Observed Flux (ergs cm^{-2} s^{-1}) (3)	f_λ (4)	Corrected Flux (ergs cm^{-2} s^{-1}) (5)	W[b] = F(O VI)/F_c (6)	Continuum Correction (7)
3820	O VI	1.9×10^{-13}	0.28	2.5×10^{-13}	290	1.05
4658 .... 4686	C IV He II	5.6×10^{-14}[c]	0.05	5.9×10^{-14}[c]	100	1.07
5434	?	3.9×10^{-15}	−0.12	3.5×10^{-15}	18	1.2

V(star) $= 17.9 \pm 0.2$

[a] $(c = 0.4 \pm 0.2)$.

[b] Corrected for nebular continuum by the factor in col. (7).

[c] $F(\lambda4658)/F(\lambda4686) \approx 2$; see text.

of ± 0.2. We list the relative line intensities corrected for this extinction, $I(\lambda) = F(\lambda)\ \mathrm{dex}(cf_\lambda)$, in column (5) of Table 1A, based on the f_λ from the Whitford function shown in column (4). Note that if the corrected Hδ intensity in Table 1 is reduced by the maximum likely N III strength, it is still 15% larger than the theoretical value, which is probably indicative of the size of the true error for similar lines. The underlying continuum is so weak that any stellar hydrogen absorption lines that may exist would have no significant effect on the relative emission-line fluxes needed for extinction. At the most, stellar absorption would cause only a 15% depression of $F(\mathrm{H}\beta)$, and more probably well under that.

The nebula, with an angular diameter of 16″, is considerably larger than the 5″ aperture used, so that we were unable to measure a total Hβ flux. We give the surface brightness determined with this aperture, that for the central region of the nebula, at the end of the table. There are no properly exposed photographs of the object. It appears as a ring in the acquisition TV, and therefore this surface brightness must be lower than the mean.

We give our measurements for the stellar emission lines in Table 1B. Columns (3) and (5) list the integrated observed and extinction-corrected fluxes in cgs units, and column (6) the equivalent width (W) relative to the flux of the underlying stellar continuum, where we make a small correction (col. [7]) for the contribution from the nebular continuum from the tables of Brown and Mathews (1970), our Hβ surface brightness (Table 1A), and our measured extinction constant. The λ3820 measurement also includes a 6% correction for the blended nebular H9 and H10 lines. In Figure 1 a weak emission feature that appears to be of stellar origin can be seen at λ5434. We can find no identification for it; it does not appear in the line lists for similar stars published by Aller (1977), and we feel that it is probably spurious. Nevertheless, we give the measurements for it in Table 1B.

Details of the λ3820 and λ4658–λ4686 stellar lines are shown in Figures 2 and 3. Deconvolution of λ3820 into its two components yields an approximate width for each line at half-maximum (FWHM) of 31 Å, or 2400 km s^{-1}, with a flux ratio $F(\lambda 3811)/F(\lambda 3834) \approx 2.3$, somewhat greater than the mean of 1.8 for resolved lines derived from Heap (1975) and Aller (1968) (see § III). A similar deconvolution of λ4658–λ4686 is complicated by nebular λ4686, but yields a similar FWHM for C IV λ4658 of ≈ 45 Å or 2900 km s^{-1}, where stellar C IV λ4658 is very roughly twice the strength of the probable stellar He II λ4686 line.

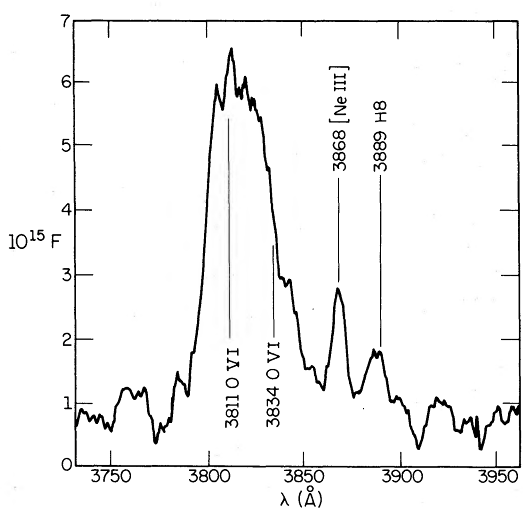

FIG. 2.—The O VI doublet in the central star of M3-30. The positions of the components are as indicated. The narrow lines on either side are nebular.

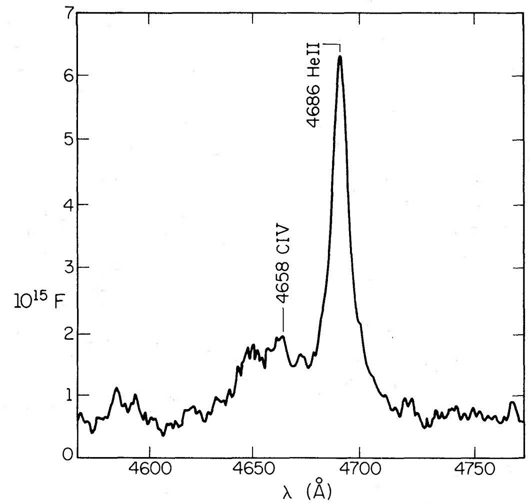

FIG. 3.—The blended C IV λ4658 + He II λ4686 feature. Nebular λ4686 is superposed upon the broad stellar profile.

Finally, from the strength of the stellar continuum at λ5500, we determine a V magnitude of 17.9, from the calibration of Oke and Schild (1970), with a 15% correction for the nebular contribution to the continuum calculated in the manner described above. The continuum, after correction for interstellar extinction (§ II*b*), rises to the blue as expected for a hot star, but the detailed agreement is not particularly good. If we fit a Rayleigh-Jeans curve at λ5500, the observed continuum rises too fast and is 30% greater than expected at λ4800; it then flattens and dips below the theoretical fit at λ3800. This variation is probably an artifact of the low signal-to-noise ratio for the weak continuum, and from it we estimate a probable error of ± 0.2 mag to the above V magnitude. Kohoutek, in Perek and Kohoutek (1967), estimated a photographic magnitude of 17.9, which given the above extinction constant, converts to a V magnitude of 18.0, with a likely error of ± 0.4 mag (Hayman, Hazard and Sanitt 1979). The two determinations are in excellent agreement, each being within the error of the other.

b) *Nebular and Stellar Parameters*

We derived the properties of the nebula and star from our and other observations and present the results in Table 2. We give the electron temperature derived from the [O III] lines and the atomic parameters listed by Mendoza (1983), at the limit of low density (see row [7]), in row (1). The temperature is somewhat elevated from the norm, consistent with the high excitation. We give the abundance of doubly ionized helium, from the above temperature and Brocklehurst's (1971) recombination coefficients, in row (2). Unfortunately, the singly ionized lines, if they exist at all, are too weak to be here observed, so that we cannot determine the actual He/H ratio. But if it is near the canonical value of 0.1, the helium is fully doubly ionized.

TABLE 2

PHYSICAL CHARACTERISTICS OF M3-30

1. T_e (Table 1)	$12{,}600^{+3400}_{-1600}$ K
2. He^{2+}/H^{+} (Table 1)	0.11 ± 0.03
3. Angular radius (Perek and Kohoutek 1967)	8″
4. Log $F(H\beta)$ (see text)	-11.86 ± 0.20
5. Distance (Cahn-Kaler)	4200 pc
6. Radius	0.17 pc
7. $\langle N_e \rangle$ (above radius)	400 cm^{-2}
8. T_z(H)	$65{,}000 \pm 12{,}000$ K
9. T_z(He II) (lower limit)	$126{,}000 \pm 14{,}000$ K
10. L_z(He II) (lower limit)	$1360 \pm 400\ L_{\odot}$
11. R_z (upper limit)	$0.082\ R_{\odot}$
12. Total O VI luminosity at star	1.4×10^{33} ergs s^{-1}
13. [L(O VI)/L(star)] (upper limit)	3.8×10^{-4}
14. O VI flux at star (lower limit)	3.4×10^{12} ergs cm^{-2} s^{-1}

In order to calculate a distance and radius from the constant-mass method, we first need the angular radius and total Hβ flux. The former, in row (3), was quoted and cited in § II*a*. The latter, in row (4), we derived from the red (Hα + [N II]) flux given by Cahn and Kaler (1971) (which was itself derived from the photographic surface brightness listed by Perek [1963]), the near-certain assumption that the [N II] contribution is negligible (based upon no observable [O II] λ3727 and the high He II λ4686 flux), the average calibration to the correct absolute fluxes given by Kaler (1983), the expected theoretical Hα/Hβ ratio of 2.85 (Brocklehurst 1971), and the calculated extinction constant. The error in log $F(H\beta)$ is unknown, but is at least ± 0.2 from Kaler's (1983) least squares analysis, which is the value we shall adopt. Note that if the total flux is calculated under the assumption that the surface flux is everywhere equal to that given in Table 1, the resulting value is 3.5 times less than that given in Table 2, consistent with our visual observation on the acquisition monitor that we were observing in a central hole of lower emission (see § II*a*). We give the resulting distance and radius, on the system used by Cahn and Kaler (1971), in rows (5) and (6). The rms electron density, based upon this radius, the stated Hβ flux, and an arbitrarily assumed filling factor, ξ, of 0.65, is in row (7).

The remainder of Table 2 gives derived properties of the central star based upon the data in Table 1. Rows (8) and (9) list the hydrogen and He II Zanstra temperatures calculated according to the scheme of Harman and Seaton (1966), where the errors were derived by propagating all the observational errors through the calculations as described by Kaler (1983). Row (10) gives the companion He II luminosity, based upon the above distance. The low value of T_z(H) implies, as usual, that the nebula is optically thin in the hydrogen Lyman continuum. Since helium appears to be doubly ionized throughout the nebula (unless He/H is much above 0.11), the gas is probably also optically thin in the He^{+} Lyman continuum, and consequently T_z(He II) is also a lower limit, and if the distance is correct (certainly a debatable point), so is L_z(He II); see Kaler (1983) for a fuller discussion. The upper limit to the stellar radius, based on T_z(He II) and L_z(He II) and their associated errors, is given in row (11).

The details of the line formation process are still obscure (see, for example, Cassinelli 1979). But since the O VI doublet is clearly produced in the stellar wind, it is important to relate the total energy in the lines to that of the star itself. Consequently, in rows (12), (13), and (14) we provide information in a variety of forms on the luminosity and emergent flux in the λ3820 O VI doublet, using the data of Table 1B, the extinction constant, calculated distance, and He II Zanstra luminosity minus the stated error. As an interesting aside, note that the flux in this one blended line approaches a solar luminosity.

The star is clearly among the hottest known and is quite luminous. According to the evolutionary calculations made by Schönberner (1981), a star with a mass under 0.56 $M_{\odot}$ cannot reach our calculated lower temperature limit (the formal value minus the error). Since the Zanstra temperature is not dependent upon distance, this value must then be a lower limit to the stellar mass that is similarly independent of distance.

III. DISCUSSION

a) *Comparison with Other Stars*

Although the M3-30 nucleus is qualitatively similar to other strong O VI stars as seen through reproductions of their spectra in Aller (1968) and Smith and Aller (1969), we would like to know how it compares with them quantitatively. We would then like to use all the numerical evaluations to see if we can uncover any correlations that may be relevant to the origin of the natures of these stars and to their states of evolution.

There are only sparse quantitative data on O VI line strengths in the literature. Aller (1948) and Heap (1975) each measured an equivalent width (W) of 1.2 Å for the λ3811–λ3834 doublet in the spectrum of the weak O VI nucleus of NGC 246, and that seems to be about all there is available. The corresponding value for M3-30 differs by a factor of over 250, illustrating a very large range. In order to increase the amount of information, we employed the photographically derived line profiles given for five stars in Aller's (1968) Figure 3. For NGC 6905 and NGC 7026 we linearized and replotted the profiles and integrated them by planimeter. For the other three (IC 1747, IC 2003, and NGC 2371), we used a simple triangular approximation. For NGC 7026 and IC 2003, which display strong nebular Balmer jumps, we were able to correct the continuum at λ3820 for the nebular contribution, with the tables of Brown and Mathews (1970). The resulting equivalent widths are given, along with those for NGC 246 and M3-30, in column (2) of Table 3. We also determined W(O VI) for Abell 30 from the scanner spectrum presented by Greenstein (1981), and to complete the table, we crudely estimated W(O VI) for NGC 1501 and NGC 5189 from the photographic spectra reproduced by Smith and Aller (1969), by visual comparison with the spectra of other stars whose equivalent widths had been measured.

Of the set of stars in Table 3, only three (NGC 5189, NGC 6905, and NGC 7026) have W(O VI) comparable to M3-30, all above 100. The errors inherent in calculating W from the nonlinear and nearly saturated spectra in Aller's (1968) Figure 3 are such that the difference of a factor of 2 between these three and M3-30 is not meaningful, and we can only conclude that all four plus perhaps the peculiar star mentioned in § I are similar as a group, and that M3-30 takes its place as one of the strongest O VI stars known. Five other stars have intermediate equivalent widths, between

TABLE 3

COMPARISON OF O VI STRENGTHS

Star (1)	W(O VI) (2)	Reference[a] (3)	10^3T(K) (4)	$L/L_\odot$ (5)	L(O VI)/L(star) (10^4) (6)	Reference[b] (7)
NGC 246	1.2	H	≥83	≥700	≤0.04	K83
NGC 1501	50:	SA	92	4400	1.1	SL, C, K
NGC 2371	50	A	≥102	≥880	≤0.8	K83
NGC 5189	500:	SA	≥102	≥370	≤8	BL, P
NGC 6905	700	A	104	3500	11	KO, C, KC, AC
NGC 7026	600[c]	A	83	2200	18	SK, KL, K
IC 1747	30	A	82	4300	0.9	K, KL, KC
IC 2003	35[c]	A	112	5900	0.5	SK, B, K, KC
Abell 30	20	G	≥70	≥440	≤0.9	K83
M3-30	290[c]	...	≥112	≥960	≤3.8	...

[a] REFERENCES AND NOTES FOR W (cols. [2] and [3]).—(A) Aller 1968, photographic. (G) Greenstein 1981, photoelectric. (H) Heap 1975, linearized photographic. (SA) Smith and Aller 1969, eye estimate from photograph.

[b] REFERENCES FOR ZANSTRA TEMPERATURES AND LUMINOSITIES (col. [7]).—(AC) Aller and Czyzak 1979. (B) Barker 1978. (BL) Blanco *et al.* 1968. (C) Collins, Daub, and O'Dell 1961. (KC) Kaler 1976*a*. (KL) Kaler and Lutz 1983. (KO) Kohoutek in Perek and Kohoutek 1967. (K) Kaler 1976*b*, 1978, unpublished. (K83) Kaler 1983. (P) Perek 1971. (SK) Shaw and Kaler 1983. (SL) Shao and Liller 1973.

[c] Corrected for nebular hydrogen lines and continuum.

10 and 100. For these, the two components are generally resolved, whereas they are intrinsically blended in the spectra of the strong O VI stars. NGC 246 stands alone, probably as a result of observational selection, as a representative of the weaker O VI stars, with W of the order of unity.

b) *Correlations*

Some correlations are known or have been suggested that involve the O VI stars as a group. Smith and Aller (1969) ventured the opinion that "the O VI doublet $\lambda\lambda$3811, λ3834 is present in emission in all WC spectra of subclass WC7 and earlier," so that the phenomenon appears temperature-related. Heap (1982) showed that the WC nebulae correlate with Greig (1971) class B nebulae, which both he and Kaler (1983) show belong to a disk population of more massive progenitors. In addition, Robinson, Reay, and Atherton (1982) demonstrate that stars of the O VI sequence are associated with nebulae with the highest expansion velocities.

With these known correlations, and with the wide range in O VI strength exhibited by these stars—perhaps a factor of 500—we might expect to find some detailed correlations between W(O VI) and other stellar parameters, from which we might learn more of the origin of this emission feature, which is clearly indicative of an extended atmosphere and steady mass loss. To that end we present for the stars of Table 3 He II Zanstra temperatures and luminosities (or their limits) and the fractional luminosities in the O VI lines, in columns (4), (5), and (6), respectively. References to the necessary observational data (apparent stellar magnitudes, Hβ and He II λ4686 fluxes, and extinction constants) are coded in column (7). The λ4686 intensity for NGC 5189 has not been measured and was set equal to that of Hβ from the appearance of the lines in the spectrum reproduced by Smith and Aller (1969). Angular diameters are from Perek and Kohoutek (1967), and the geometric filling factors (ξ; see Harman and Seaton 1966) were set at unity, in accord with Kaler (1983). We took T and L for NGC 246, NGC 2371, and Abell 30 directly from the last reference, and as adopted there, we considered T and L to be lower limits if He II λ4686 was stronger than 0.9F(Hβ), implying low optical depth in the He^+ Lyman continuum. The fractional luminosity in O VI, L(O VI)/L(star), was computed by multiplying W(O VI) by $L(\lambda3820)/L(\text{star}) = \pi B(\lambda)d\lambda/\sigma T^4$, where $B(\lambda)d\lambda$ is the Planck function at λ3820, which is equivalent to the procedure used earlier for M3-30. All the O VI stars listed here have high luminosities, which we can add to the list of correlations that treat these stars as a group, and which is consistent with the existence of the extended atmospheres implied by the stellar emission lines. They all also have the high temperatures appropriate to their early spectral types, as previously indicated. Those of NGC 5189 and NGC 6905 are near 100,000 K, considerably higher than the 60,000 K suggested by Johnson (1981) from *IUE* data.

In spite of what originally may have been anticipated there are no correlations evident from Table 3 between the strength of O VI and either T or L. The strong O VI stars occupy the full range of temperature and luminosity, as do those of intermediate O VI strength. For example, among the former group, NGC 7026 has one of the lowest central star temperatures, and M3-30 the highest; NGC 5189 has the lowest Zanstra luminosity (which is, however, a lower limit), and NGC 6905 the fourth highest. NGC 7026 also has a weak He II λ4686 line, only 10% of the Hβ line strength, whereas the other three nebulae with strong O VI stars have comparable Hβ and λ4686 line fluxes, as do three of the nebulae with intermediate-strength O VI stars (NGC 1501, NGC 2371, and Abell 30), and NGC 246. And although the O VI nuclei generally are associated with rapidly expanding nebulae, there is no detailed correlation between the O VI line strength and the expansion velocities listed by Robinson, Reay, and Atherton (1982) and by Sabbadin and Hamzaoglu (1982).

The lack of correlation may be the result of a number of factors, chief among which is the small number of stars considered in Table 3. And compounding the problem, we have only lower limits for T and L for half of the 10 stars listed there. In addition, observational selection is important. Only a minority of planetaries have had their nuclei classified. Many stars, especially those with the hotter and/or more luminous nuclei, which systematically have higher core masses, are enmeshed in nebulosity so bright that the stars are difficult, if not impossible, to observe. Then, of course, one must consider serious uncertainties in the distances (see Kaler 1983). Finally, only three of the stars have accurately measured O VI equivalent widths. Given these problems, any correlations that may genuinely exist may easily be lost.

A major purpose of this paper is to point out the lack of quantitative data for these and other emission-line planetary nuclei and to use our observations of M3-30 as an example of the sort of data that are required. We need to find many more of these stars and to make accurate quantitative measurements of the stellar magnitudes, energy distributions, and emission-line fluxes and widths, so that their mass-loss rates, excitation conditions, and locations on the log L–log T plane can be determined. Only then can we begin to uncover their relation to other types of stars and to the whole picture of post-AGB stellar evolution.

This research was supported by NSF grant AST 80-23233 to the University of Illinois. We would like to thank the staff of Steward Observatory for their help in obtaining and reducing the data, J. S. Gallagher and D. Hunter who generously provided us with some of their allocated observing time, the latter individual and S. Kenyon for providing their interactive spectral analysis program, and L. H. Aller for helpful comments.

REFERENCES

Aller, L. H. 1948, *Ap. J.*, **108**, 241.
———. 1968, in *IAU Symposium 34, Planetary Nebulae*, ed. D. E. Osterbrock, and C. R. O'Dell (Dordrecht: Reidel), p. 339.
———. 1977, *J.R.A.S. Canada*, **71**, 67.
Aller, L. H., and Czyzak, S. J. 1979, *Ap. Space Sci.*, **62**, 397.
Barker, T. 1978, *Ap. J.*, **219**, 914.
Blanco, V., Kunkel, W., and Hiltner, W. A. 1968, *Ap. J.* (*Letters*), **152**, L137.
Blanco, V., Kunkel, W., Hiltner, W. A., Chodil, G., Mark, H., Rodriques, R., Seward, F., and Swift, C. D. 1968, *Ap. J.* (*Letters*), **152**, L135.
Brocklehurst, M. 1971, *M.N.R.A.S.*, **153**, 471.
Brown, R. L., and Mathews, W. G. 1970, *Ap. J.*, **160**, 939.
Cahn, J. H., and Kaler, J. B. 1971, *Ap. J. Suppl.*, **22**, 319.
Cassinelli, J. P. 1979, *Ann. Rev. Astr. Ap.*, **17**, 275.
Collins, G. W., II, Daub, C. T., and O'Dell, C. R. 1961, *Ap. J.*, **133**, 471.
Freeman, K. C., Rodgers, A. W., and Lyngå, G. 1968, *Nature*, **219**, 251.
Greenstein, J. 1981, *Ap. J.*, **245**, 124.
Greig, W. E. 1971, *Astr. Ap.*, **10**, 161.
Harman, R. J., and Seaton, M. J. 1966, *M.N.R.A.S.*, **132**, 15.
Hayman, P. G., Hazard, C., and Sanitt, N. 1979, *M.N.R.A.S.*, **189**, 853.
Heap, S. R. 1975, *Ap. J.*, **196**, 195.
———. 1982, *IAU Symposium 99, Wolf-Rayet Stars: Observations, Physics, Evolution*, ed. C. W. H. de Loore and A. J. Willis (Dordrecht: Reidel), p. 423.
Johnson, H. M. 1975, *Ap. J.*, **198**, 111.
———. 1981, *Ap. J.*, **250**, 590.
Kaler, J. B. 1976*a*, *Ap. J. Suppl.*, **31**, 517.
———. 1976*b*, *Ap. J.*, **210**, 113.
———. 1978, *Ap. J.*, **226**, 947.
———. 1983, *Ap. J.*, **271**, 188.
Kaler, J. B., and Lutz, J. H. 1983, in preparation.
Mendoza, C. 1983, in *IAU Symposium 103, Planetary Nebulae*, ed. D. Flower (Dordrecht: Reidel), p. 143.
Oke, J. B., and Schild, R. E. 1970, *Ap. J.*, **161**, 1015.
Paczyński, B. 1971, *Acta Astr.*, **21**, 417.
Perek, L. 1983, *Bull. Astr. Czechoslovakia*, **14**, 201.
———. 1971, *Bull. Astr. Czechoslovakia*, **22**, 103.
Perek, L., and Kohoutek, L. 1967, *Catalogue of Galactic Planetary Nebulae* (Prague: Czechoslovakia Academy of Science).
Robinson, G. J., Reay, N. K., and Atherton, P. D. 1982, *M.N.R.A.S.*, **199**, 649.
Sabbadin, F., and Hamzaogln, E. 1982, *Astr. Ap.*, **110**, 105.
Schönberner, D. 1981, *Astr. Ap.*, **103**, 119.
Shao, C.-Y., and Liller, W. 1973, private communication.
Shaw, R. A., and Kaler, J. B. 1983, in preparation.
Smith, L. F., and Aller, L. H. 1969, *Ap. J.*, **157**, 1245.
Whitford, A. E. 1958, *A.J.*, **63**, 201.

JAMES B. KALER and RICHARD A. SHAW: 341 Astronomy Department Building, University of Illinois at Champaign-Urbana, 1011 West Springfield Avenue, Urbana, IL 61801-3000