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THE CENTRAL STAR OF NGC 1514

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ABSTRACT

The large planetary nebula NGC 1514 has a central star classified as A0; the star's continuum was known to be composite. Coudé spectra show the presence of stellar He II absorption, making it possible to resolve the stellar continuum into a horizontal-branch A star and a visually subluminous O star. Spectrophotometry of Balmer lines gives the surface gravity of the HB A star and thus its luminosity as $M_V = +0.8$; the O star has $M_V = +2.8$. If we adopt the parameters of the nebula from Kohoutek, the ultraviolet luminosity of the O star requires $T \approx 100{,}000°$ K, and $M_b = -3.8$, typical of a normal planetary nucleus. The velocity of the A star is constant, near $+48 \pm 2$ km s^{-1}; a redetermination of the nebular velocity gives accordant results, $+41 \pm 5$ km s^{-1}.

I. INTRODUCTION

My study of horizontal-branch stars and hot subdwarfs had suggested a linkage of their evolutionary paths to that of the nuclei of planetary nebulae. In addition, it had suggested that the bolometric luminosities hardly changed along the entire extended horizontal branch, remaining near $M_b = 0.0$ (Greenstein 1970, 1972). Many nuclei of planetary nebulae are much more luminous, and a few are spectroscopically peculiar. A most interesting object is the nucleus of NGC 1514, which has been classified as an A0 to B8 star. The problems and history of this star, which is +30°623, are given by Kohoutek (1967) and Kohoutek and Hekela (1967). They conclude that the star is an unresolved double consisting of an A0 giant and a hot subdwarf. The nebula is close to the galactic plane (166°, −15°) and is highly reddened with $A_V \approx 2.0$ mag. Liller and Shao (1968) also find the object composite in continuous energy distribution.

Fortunately, we have available five Palomar coudé spectrograms at 18 Å mm^{-1} and two Mount Wilson at 10Å mm^{-1} (one underexposed). Inspection clearly demonstrates that λ4686 of He II is seen at both these dispersions, so that the presence of a hot star of low visual luminosity is demonstrated, in agreement with the deductions made by Kohoutek from *UBV* photometry, and of Kohoutek and Hekela from photographic spectrophotometry of the continuum. Thus, there is no doubt that a hot object exists to provide ultraviolet flux responsible for the ionization of NGC 1514, i.e., that the planetary nebula does have a hot central star. Five Mount Wilson low-dispersion spectra exist at 40 and 80 Å mm^{-1}. These were taken by Hubble in 1920 and show nothing of interest beyond the presence of λλ4686, 4481 and possibly a few weak He I lines. Their mean velocity was $+30 \pm 3.5$ km s^{-1}. Their systematic accuracy cannot be judged; they are unwidened, and it is hard to see weak lines. The hydrogen cores should be usable for velocity.

The new spectra have been measured for velocity with results shown in table 1. The velocities of the hydrogen lines agree with the metals; that of λ4686 shows a mean velocity difference of -7 ± 5 km s^{-1}. In addition, what seemed to be a sharp He II line at λ4542 (an astrophysical anomaly) is in fact Fe II, whose sharp lines are seen at λλ4179, 4233, and in a blend at λ4550. The λ4481 Mg II line is also quite sharp at 10 Å mm^{-1}, so that the rotational broadening is less than 50 km s^{-1}. On all 18 Å mm^{-1} plates the ionized metallic lines seem sharp. Therefore, we can conclude that the A star is not rotating more

TABLE 1

SPECTROSCOPIC DATA ON THE CENTRAL STAR OF NGC 1514, +30°623

DATE (UT)	PLATE	VELOCITY (km s^{-1})		OBSERVER	LINES SEEN
		Star	λ3933		
1949 December 27, 4^h35^m..	Ce 6070	+49	+38	O. C. Wilson	H, He II, Mg II
1949 December 29, 3^h50^m..	Ce 6074	(+44)	(+41)	O. C. Wilson	H, Mg II, slitless? (poor plate), K looks double
1968 February 7, 3^h43^m....	Pd 10418	+48	+40	Deutsch	Hβ–H15; He II, Mg II, Si II
1968 September 5, 10^h35^m..	Pd 10691	+52	+32	Münch	Hβ–H14; He II, Mg II, Fe II, Si II, Ti II
1971 February 7, 5^h47^m....	Pd 12163	+47	+27	Greenstein	Hβ–H11 (−UV filter); He II, Mg II, Fe II, Si II, Ti II
1971 March 31, 4^h05^m......	Pd 12254	+42	+30	Greenstein	Hβ–H9, He II, Mg II, Fe II, Ti II
Mean.................		+47.6 ± 1.6	+34 ± 3		

rapidly than 40 km s^{-1}. From the Kohoutek analysis, the flux in the A star is 4 times that in the O at the *B*-wavelength; it is 0.75 as bright at the *U*-wavelength. Thus, most metallic lines should be largely unaffected by the O star. Furthermore, the presence of the λλ3856, 3863 lines of Si II suggests that the O-star flux is even somewhat weaker than Kohoutek determines. Further evidence of the O star's faintness is provided by the visibility of Balmer lines out to H14 or H15 on the 18 Å mm^{-1} plates. Such lines cannot arise in a sdO star, which has broad and weak hydrogen series normally terminating near H11 or H12.

The results from all lines except Ca II give a mean velocity near +47.6 ± 1.6 km s^{-1}. My good high-dispersion plates show no sign of velocity variation. There have been some moderate-dispersion measurements of the star's velocity. Kohoutek (1968) quoted preliminary measures at Asiago ranging from +60 to +86 km s^{-1} with internal errors of ±8 km s^{-1}; Mammano, Margoni, and Perinotto (1968) give a range from +35 ± 10 to +95 ± 10 km s^{-1} from Asiago plates.

The discrepancy of my mean with the published nebular velocity, +71 km s^{-1} (Chopinet 1963), was puzzling. An electronic camera had been used and 10 plates obtained. The dispersion was low (given as 1 μ = 17 km s^{-1} at Hβ, or 270 Å mm^{-1}), but her velocities of other nebulae agreed well with published values (±5 km s^{-1}) except for one other large discrepancy. The lack of detail published on the stellar velocity and its variation suggested by Asiago plates is unfortunate; their gross mean is close to that published for the nebula, while my high-dispersion spectra differed by −23 km s^{-1} from that of the nebula, a rather unexpected result.

The surface brightness of NGC 1514 is low; it is nearly invisible at the coudé focus and suffers absorption of about 2 mag at Hβ. Three different spectrographs were now used, with results shown in table 2. The region observed was 1 minute south of the central star; lines found were [O III], [Ne III], [Ar IV], [S II], He II, He I, and hydrogen. The mean is +41 ± 4 km s^{-1}, almost identical with the star. Seven lines were found on each plate, in spite of different spectral regions (Hα to λ3868) used. The agreement is fair, although none of these spectra are of outstanding high quality, nor have either of the first two systems been tested for systematic errors. The coudé image-tube spectra were taken with an experimental arrangement using an ITT 4089 magnetic-focusing, fiber-optics tube. The surface brightness of the nebula is so low that these spectra showed infrared Ne I lines for the first time, reflected from the sky.

TABLE 2

VELOCITY OF NGC 1514

Spectrograph	Dispersion ($Å\ mm^{-1}$)	Velocity ($km\ s^{-1}$)	Remarks
Coudé image tube..............	20, 30	$+45\pm5$	Two; film
Cassegrain image tube..........	80	$+41\pm8$	One plate; corrected for curvature and nightsky line positions
Prime-focus, photographic......	90	$+33\pm8$	Same
Mean......................		$+41\pm5$	

If the nebular and stellar velocities are in fact the same, and near +45 km s^{-1}, then the velocity of the K-line in table 1 is interesting. It differs from the mean stellar velocity by -14 ± 5 km s^{-1}. The expected interstellar line velocity (from solar motion and galactic rotation) is +3 km s^{-1} at 500 pc distance. The blend observed is closer to the stellar than to the interstellar velocity, i.e., the A star has a reasonably strong stellar K-line. The presence of other relatively strong ionized metallic lines, and sharp Balmer lines, almost certainly suggests a horizontal-branch A star (A3–A5) with the weak lines characteristic of the halo population.

If the star is a velocity variable, as suggested by other observers and by the possible difference between my mean stellar and nebular velocities, the plausible semiamplitude would be at most 25 km s^{-1}. For two horizontal-branch stars of 0.7 $\mathfrak{m}_{\odot}$, the separation would be 1 a.u., period 1 year, and maximum separation 0″.002. Even then, the constancy of the stellar velocities in table 1 is surprising; it is more probable that the system is an as yet unresolved binary of much larger period and smaller velocity amplitude. Given this assumption, the system becomes important in that it can give a quite accurate luminosity for the central star of a planetary nebula.

II. RESULTS FROM THE SPECTROPHOTOMETRY OF LINES AND CONTINUUM

A quantitative analysis of the A-star spectrum is complicated by the composite nature of the continuum. The major goal of this section is to ascertain whether the two stars are a physical binary, not a chance optical pair. If both prove to be members of the extended horizontal branch (Greenstein 1970), they should have nearly the same bolometric luminosity. Were the A star isolated, its surface gravity and temperature would be determined by the energy distribution, Balmer jump (BJ), and the line profile of Hγ (see Kodaira, Greenstein, and Oke 1969). There, we analyzed the early A stars HD 86986, 109995, 161817 quantitatively. The star in NGC 1514 is somewhat hotter than these; $\lambda3933$ Ca II has an equivalent width 0.45 Å, uncorrected for the interstellar component, as compared to 0.70 Å in HD 109995 ($\theta = 0.63$), or 1.00 Å in HD 86986 ($\theta = 0.66$). The $\lambda4481$ Mg II line has $W = 0.24$ Å, about the same in all three. The Fe II lines are weak, so that all the stars are metal poor. The $\lambda4686$ He II line, however, has $W = 0.40$ Å, with a central depth $A_c = 0.10$, and a half-width of 4 Å. The half-widths of $\lambda\lambda4481, 4233, 3933$ are about 1.2 Å, without correction for the instrumental resolution of about 0.4 Å. Thus, we see only the central portion of $\lambda4686$, which must be quite strong in the O star.

First we analyze the Balmer-line profile in the A star, without correction for the composite spectrum, to estimate its surface gravity and mass-luminosity ratio. The profile of Hγ from an 18 Å mm^{-1} plate is shown in figure 1. It has a total width at 20 percent absorption, $\log D(0.2) = 1.38$. My own grid of model atmospheres (which stops at $\theta \leq 0.50$) gives $\log g = 3.4$ for $\theta = 0.50$. From Newell's thesis (1969) we find values of $\log g = 4.0, 3.6, 3.1$ for $\theta = 0.45, 0.50, 0.55$. Finally, the H$\gamma$ profiles are similar to those

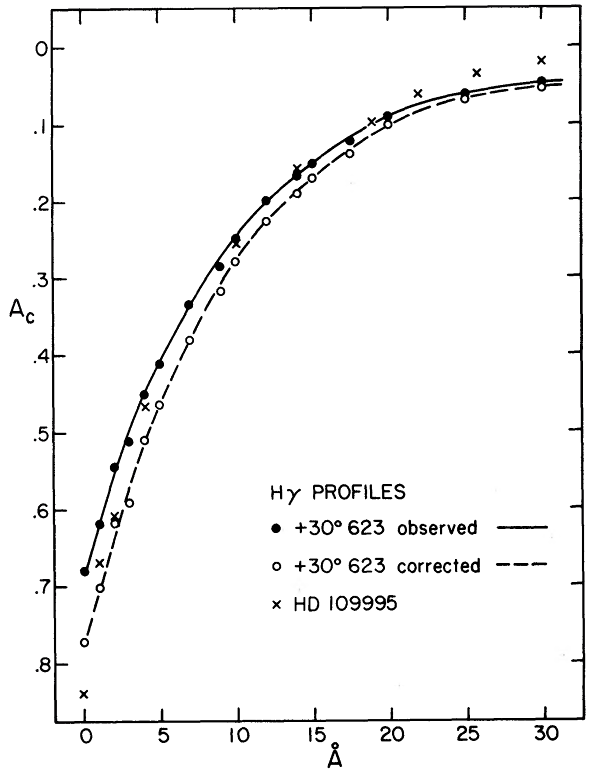

FIG. 1.—The profile of Hγ (*dots*) in +30°623 as observed, compared to that in the horizontal-branch A star HD 109995 (*crosses*). The dashed profile in +30°623 is corrected for the light of the invisible hot star.

in HD 109995 (fig. 1); Hγ is shallower and slightly broader. From this analogy, we could say the stars are the same, as cool as $\theta = 0.63$, where $\log g = 2.8$.

The first results are sufficiently encouraging to justify an attempt to allow for the overlapping continuum and lines of the O star. Call the A-star flux $F_\lambda(1)$, the O-star flux $F_\lambda(2)$, with $F_\lambda(2) = r_\lambda F_\lambda(1)$. Here we define r_λ, near any line, as the ratio of fluxes in the two continua ($r_\lambda < 1$ probably). Let the true absorption profiles in each star be a_λ and the flux in the continuum near a line be F_c, i.e.,

$$a_\lambda(1) = 1 - [F_\lambda(1)/F_c(1)]\,, \tag{1a}$$

$$a_\lambda(2) = 1 - [F_\lambda(2)/F_c(2)]\,. \tag{1b}$$

If the O star also has a hydrogen line, we will assume for simplicity that it has the same profile, $a_\lambda(2) = \beta a_\lambda(1)$ ($\beta < 1$). Then the composite spectrum has a line with observed profile

$$A_\lambda = \frac{a_\lambda(1)(1 + \beta r_\lambda)}{1 + r_\lambda}\,, \tag{2}$$

which permits us to compute

$$a_\lambda(2) = \frac{1 + r_\lambda}{r_\lambda} A_\lambda \text{ (if } a_\lambda(1) = 0)\,, \tag{3a}$$

or

$$a_\lambda(1) = \frac{1 + r_\lambda}{1 + \beta r_\lambda} A_\lambda\,. \tag{3b}$$

In these formulae, r_λ refers to the ratio of continua, but a_λ to the profile within the lines; r_λ changes slowly and can be estimated by spectrophotometry of the continuum and the relative energy distributions in the two stars. The results in table 3 show how well r can be determined. Equation (3b), with $\beta = 0$, gives the true profile of λ3933, for example, while equation (3a) gives the λ4686 profile. Since both θ and g differ, it is unlikely that the higher members of the Balmer series can be represented by so simple an assumption as that β = constant. With $\beta \approx 0.3$, $r \approx 0.2$, the composite profile gives $a_\lambda(1) = 1.13\ A_\lambda$, i.e., the true depth is 13 percent greater than that observed, which is not inconsistent with the comparison in figure 1 of Hγ in HD 109995 and the NGC 1514 star. These estimates are useful and are based on the maximum possible filling in of Hγ in the A star. For lines with $\beta = 0$—e.g., λλ3933, 4481—$a_\lambda(1) = 1.2\ A_\lambda$, which seems not unreasonable. Conversely, from equation (3a) the λ4686 profile, and therefore its observed equivalent width, should be multiplied by 6, for $r = 0.2$. This seems as high a value as is possible, giving a central absorption of 60 percent in an O star, which is probably too high.

We may use the central depths of the higher Balmer lines to see whether the O star begins to fill in their cores. The observed central absorption A_c of Hβ, Hγ, and Hδ are 0.78(?), 0.69, and 0.69; the plate is underexposed beyond H8, but H7, H8, H9, H10, and H11 have A_c's of 0.67, 0.55, 0.50(?), 0.40(?), and 0.36(?). Since Balmer lines in horizontal-branch stars begin to merge at $n = 16$, the decrease in central absorption observed is partly that expected in a single star and partly that caused by a hot overlying continuum. In a high-surface-gravity O star, lines disappear near $n = 12$. We might take $\beta = 0$, at $n = 11$, and use equation (2) to evaluate the maximum possible value of r_λ at λ3800. We derive the expected undisturbed $a_c(1)$, the central depth of H10 to be at maximum 0.66, based on high-dispersion tracings of a cooler, unreddened horizontal-branch A star,

TABLE 3

PREDICTION OF COMPOSITE SPECTRUM

1/λ (1)	λ (2)	HD 109995 $m_v(1)$ (3)	O Star $m_v(2)$ (4)	$\delta m(i)$ (5)	$\Delta(i)$ (6)	$\delta m(j) = \delta m(i) + 0.75$ (7)	$\Delta(j)$ (8)	$\delta m(k) = \delta m(i) + 1.50$ (9)	$\Delta(k)$ (10)	Solution (j) Predicted Magnitude m_v (11)
2.95.....	3390	2.42	1.21	−1.21	−1.51	−0.46	−1.00	+0.29	−0.60	1.42
2.90.....	3448	2.40	1.25	−1.15	−1.48	−0.40	−0.97	+0.35	−0.59	1.43
2.85.....	3509	2.36	1.30	−1.06	−1.41	−0.31	−0.91	+0.44	−0.55	1.45
2.80.....	3571	2.35	1.33	−1.02	−1.38	−0.27	−0.88	+0.48	−0.54	1.47
2.75.....	3636	2.32	1.37	−0.95	−1.33	−0.20	−0.85	+0.55	−0.51	1.47
2.70.....	3704	2.15	1.42	−0.73	−1.17	+0.02	−0.74	+0.77	−0.43	1.41
2.62.....	3800	(1.00):	1.48	+0.48	−0.54	+1.23	−0.30	+1.98	−0.26	0.70:
2.52.....	3970	(0.80):	1.57	+0.77	−0.43	+1.52	−0.24	+2.27	−0.15	0.56:
2.48.....	4032	0.81	1.60	+0.79	−0.41	+1.54	−0.23	+2.29	−0.15	0.58
2.40.....	4167	0.83	1.67	+0.84	−0.41	+1.59	−0.22	+2.34	−0.14	0.61
2.35.....	4255	0.84	1.71	+0.87	−0.40	+1.62	−0.22	+2.37	−0.13	0.62
2.24.....	4464	0.85	1.82	+0.97	−0.37	+1.72	−0.20	+2.47	−0.12	0.65
2.19.....	4566	0.86	1.87	+1.01	−0.36	+1.76	−0.20	+2.51	−0.11	0.66
2.09.....	4785	0.88	1.97	+1.09	−0.33	+1.84	−0.18	+2.59	−0.09	0.70
2.00.....	5000	0.90	2.07	+1.17	−0.32	+1.92	−0.17	+2.67	−0.08	0.73
1.90.....	5263	0.92	2.17	+1.25	−0.31	+2.00	−0.16	+2.75	−0.08	0.76
1.80.....	5556	0.95	2.29	+1.34	−0.28	+2.09	−0.15	+2.84	−0.07	0.80
r(3800).	...	...	...	0.65	...	0.32	...	0.16	...	...
r(4340).	...	...	...	0.43	...	0.21	...	0.11	...	...
ΔBJ....	...	...	...	−0.96	...	−0.66	...	−0.39	...	...

HD 109995; the uncertain values for A_c for H9–H11 suggest $A_c = 0.40$. We find then that $r \leq 0.65$ at λ3800 Å.

The continuum of HD 109995 permits us to reconstruct the expected fluxes beyond the Balmer limit. A simple continuum for the O star is a blackbody at infinite temperature, $F_\nu(2) \propto \nu^2$. We first assumed the O-star flux to be 0.65 that of the A star at 3800 Å, and evaluated the first trial differences of magnitude, $\delta m_\nu(i)$, given in column (5) of table 3. The HD 109995 flux was not measured near the higher Balmer lines; the absolute flux drops by 1.34 mag between λ4032 and λ3704.

From a first trial $r_\lambda(3800)$ we tabulate $\delta m(i)$, the magnitude difference between the O and the A star at all wavelengths. For the composite magnitude of the two stars we compute $\Delta_\nu(i)$,

$$m_\nu(1+2) = m_\nu(1) + \Delta_\nu(i) = m_\nu(1) - \tfrac{5}{2}\log_{10}\{1 + \mathrm{dex}[-0.4\delta m_\nu(i)]\} . \qquad (4)$$

In table 3 we list three approximations, $\delta m(j) = \delta m(i) + 0.75$ and $\delta m(k) = \delta m(i) + 1.50$, with their $\Delta\nu(i)$, $\Delta\nu(j)$, $\Delta\nu(k)$. The composite predicted fluxes are not tabulated, since all we need is the tabulated reduction of the Balmer jump, ΔBJ, from the run of the Δ's just before and after λ3647. For $1/\lambda = 2.48$ to 2.35, $\Delta(i)$ is -0.41, while for $1/\lambda = 2.85$ to 2.75 it is -1.37, i.e., the Balmer jump is reduced by $\Delta \mathrm{BJ} = -0.96$ mag. This is clearly too large, so trials j and k were made with the O star 2 and 4 times fainter. The computed values $\Delta(j)$ and $\Delta(k)$ give reductions, ΔBJ, of -0.66 and -0.39 mag.

The photographic spectrophotometry of Kohoutek and Hekela (1967) shows that the observed ΔBJ is about -0.5 mag. But the star is so highly reddened that ΔBJ could be quite strongly affected by changes in the reddening. They estimate $r_\lambda(3800) = 0.76$, while table 3 gives 0.64, 0.32, 0.16 for my three cases. However, a solution with $r_\lambda(4340) = 0.43$ is quite acceptable. From equation (3b), with $\beta = 0.3$, $a_\lambda(1) = 1.27\ A_\lambda$, so the observed central depth of Hγ, 0.69, corresponds to an A-star depth of 88 percent, unreasonably large. Apparently the O-star brightness has been overestimated by earlier workers. The solution $\delta m(j)$ gives $a_\lambda(1) = 1.14\ A_\lambda$, which is possibly acceptable. Then $r_\lambda(3800) = 0.32$, so that the lines H10 and H11 have their central absorptions reduced by 23 percent. This is perhaps insufficient, but still acceptable. Solution $\Delta(k)$ makes the O star so faint that it is detectable only through the reduction of the BJ, and we will use solution (j) hereafter; the final magnitudes are given in the last column of table 3. The spectrum is very flat, except for a BJ of about 0.85 mag. Note that δm at λ5556 is about +2.0, i.e., the O star has $M_V = M_V(A) + 2.0$.

III. LUMINOSITY AND TEMPERATURE

The bolometric luminosity of horizontal-branch A and B stars is determined, subject to uncertainties in their mass, from

$$M_b = 2.5 \log g + 10 \log \theta - 2.5 \log m/m_\odot - 5.82 . \qquad (5)$$

From θ and g the mass-luminosity ratio is $\log (m/m_\odot)/(L/L_\odot) = -2.03$ for HD 86986, 109995, 161817. For 1 $m_\odot$, $\langle M_V \rangle = -0.50$, while for 0.5 $m_\odot$, $\langle M_V \rangle = +0.25$. We should correct the analysis of Hγ in the horizontal-branch A star in NGC 1514 by using the predicted filling in of Hγ. If solution (j) is used, then $r_\lambda(4340) = 0.21$, and even with $\beta = 0.3$ the profile is considerably widened. Instead of $D(0.2) = 24$ Å, we find $D(0.2) = 27$ Å, which corresponds to $\log g = 3.9$, 3.2, 3.1 for $\theta = 0.50$, 0.55, 0.60, from Newell's models. With $m = 0.5\ m_\odot$, these correspond to $M_b = +1.7$, +0.5, -0.1; from my models at $\theta = 0.50$, $\log g = +3.7$ and $M_b = +1.2$. Since the A star is hotter than the three field stars, it seems best to adopt a value of θ near 0.55 and we can then fix $M_b = +0.5$, with an uncertainty of ±0.5, which means that $M_V = +0.8 \pm 0.5$. Finally, the

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M_V of the O star is $+2.8 \pm 0.7$, where we doubled the sources of error by our uncertainty as to whether $\delta m(j)$ or $\delta m(k)$ is the best approximation to the magnitude differences.

Whether so faint an absolute visual magnitude is correct depends on the unknown temperature of the O star, since the bolometric correction varies steeply with θ. We have decreased the luminosity of the A star from that assumed by Kohoutek and Hekela (1967) by 1.5 mag, but found the difference of visual magnitudes essentially the same, so that we derive M_V for the O star 1.6 mag fainter than they do. Earlier classification of the A star as a giant is incorrect; part of the difference between a horizontal-branch A star and an A giant comes from the higher mass of the latter. However, we cannot reconcile Kohoutek's (1967) $M_V = -1.4$ with the spectrophotometrically determined $\log g$. The change of 0.8 in $\log g$ would reduce $D(0.2)$ from the measured 24 Å to 13 Å. The overlapping O star can only increase the value of $a_\lambda(1)$ above that observed. From equation (5), at constant $\log g$, the increase of luminosity to an A giant would multiply the mass by more than 4, giving for the horizontal-branch A star 3.3 $m_\odot$, which is implausible for a weak-lined star, even with extensive mass exchange. If ever any orbital motion is found, the high mass can be tested, since the velocity is $\approx 20\, r^{-1/2} m^{1/2}$ km s^{-1}, with r in a.u. and m the sum of the masses in solar units. A visual binary of $0''.5$ separation gives only 1.2 $m^{1/2}$ km s^{-1} velocity. Only an unusually massive star could produce radial-velocity changes. In résumé, the most plausible hypothesis is that the O star is visually faint, very hot, and a member of a metal-poor binary. It then falls near the luminosity and color of the faint hottest stars on the horizontal branch of, for example, M13, or on the hot end of the extended horizontal branch (EHB) noted by Greenstein (1970) for field stars of the galactic halo. Then the star in NGC 1514 could be a low-luminosity nucleus of a faint planetary, rather than like the typical brighter central stars. Figure 2 shows schematically the location of halo stars so derived, together with the positions of the A and O components of the star; the O star (here lying on the line BB') proves bolometrically bright, in fact.

The equivalent width W_λ of the He II line is observed to be 0.40 Å. From our adopted magnitude differences at λ4686 (table 3) we derive (eq. [3]) W_λ in the O star as 2.50 Å. In a hot sdO, I find λ4686 in the range 1–3 Å, since the apparent He I weakness in

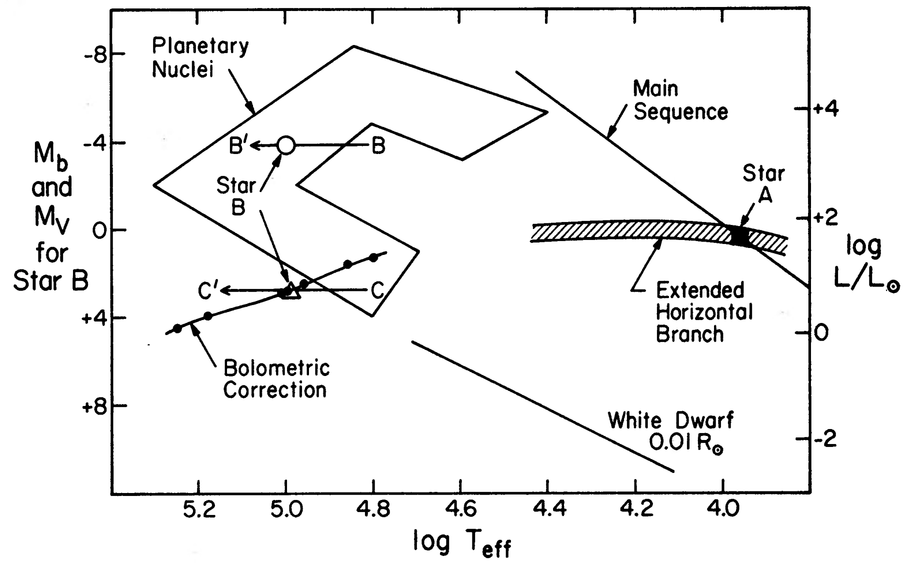

FIG. 2.—Schematic location of hot stars and of the components of +30°623. Star A, the horizontal-branch A star, is shown by the large square; star B, the sdO, must lie on the line BB'; the line CC' is the absolute visual magnitude deduced for star B. The bolometric-correction locus intersects CC' at 100,000° K, where the open triangle indicates the M_V and the open circle the M_b of star B.

horizontal-branch B stars is not accompanied by a He II weakness in sdO stars. The corrected W_λ is not very well determined since it is possible that only the core of the line is measurable in the composite spectrum.

The bolometric correction is so steep a function of the effective temperature that the sdO star can provide sufficient ultraviolet radiation to maintain the nebular luminosity over a wide range of parameters. Kohoutek's (1967) excellent discussion need be modified only by noting that the total radiation of a blackbody varies as T^4 while its radiation in the visible varies as T. Since we have increased the absolute visual magnitude of the O star by 1.6 mag, we could either increase the absolute value of the bolometric correction by the same amount or increase the ultraviolet optical depth of the nebula. In a rough way, the ratio of ultraviolet to visual light in a very hot star is proportional to T^3, so that the bolometric correction changes by about $3dT/T$; i.e., we need $dT/T \approx 0.5$. Using bolometric corrections ΔM_b given by Böhm (1969), we will find from his models that $T_* \approx 100{,}000°$ K.

In figure 2 we show the location of the main sequence (MS), white dwarfs (W.D.) and, in the open area, the nuclei of planetary nebulae. The halo extended-horizontal-branch (EHB) stars terminate in a scatter diagram of hot sdO stars, whose temperatures are all, given from colors, near 40,000° K for lack of a better determination at high $T_{\rm eff}$. Star A of +30°623 is at the right-hand end of the plotted EHB A stars. The M_b of star B, the hot subdwarf required by the nebular line fluxes, is shown as a line running to the left of point B (Kohoutek's value), which we will adopt as fixed correctly by his analysis. Note that the line CC' is the newly observed M_V (even though plotted on the M_b scale for convenience). The plotted small dots and curve are derived by subtracting Böhm's bolometric correction from the M_b required, and predict M_V as a function of $T_{\rm eff}$. Note that the intersection of this curve and the line CC' gives the value of $T_{\rm eff} \approx 100{,}000°$ K. Here, for star B, $M_b(\text{Nebula}) - \Delta M_b(T_{\rm eff}) = M_V(\text{This investigation})$. Then the large open circle plotted on the line BB' is the final position for the subdwarf O (star B). It lies well within the normal region where planetary nuclei are found; it is much brighter than star A. The uncertainties are at least ± 0.7 mag and ± 0.1 in log T; but in many ways the determination of the location of this star on the (M_b, $T_{\rm eff}$)-diagram is a good one for a planetary nucleus even though the star has not been seen.

Little information is provided by the proper motion. The mean values given are discrepant internally and externally. The most that can be said is that the motion is small. There is little point in recomputing the reddening, which was studied by Kohoutek, except that we have made the A star 4 times fainter. We have reduced his distance by a factor of 2, giving a distance of 240 pc. We then expect a proper motion of 0″.020 or larger, suggesting the importance of an accurate new determination. Star B is not on the extension of the horizontal branch, but lies in the normal range of the nuclei of planetary nebulae.

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HISTORICAL NOTE

NGC 1514 has particular importance in the history of astronomy, as W. L. W. Sargent kindly informed me. Hoskins (1963) quotes William Herschel (1791) writing "On Nebulous Stars, properly so called." Herschel noted that improvements in telescopes resolved most "nebulous" stars into crowds of fainter stars, i.e., galactic and globular clusters. He felt that even the Orion Nebula might consist of unresolvable fainter stars, since there were many visible stars superposed on the nebulosity, whose numbers increased at fainter magnitudes. However, NGC 1514, observed in 1790, made him write: ". . . a star of about the 8th magnitude, with a faint luminous atmosphere, of a circular form,

. . . The star is perfectly in the center, and the atmosphere so diluted, faint and equal throughout, that there can be no surmise of its consisting of stars; nor can there be a doubt of the evident connection between the atmosphere and the star. . . . we therefore either have a central body which is not a star, or a star which is involved in a shining fluid, of a nature totally unknown to us." The nature of that gaseous fluid is still being elucidated. It would be interesting to know whether the present V-magnitude, 9.5, represents a real change due to the fading of the O star. Evolutionary times for sdO stars are shortened by neutrino energy loss, but 200 years still seems too short a timescale. Herschel experimented with two telescopes of different apertures, to determine magnitudes quantitatively, beginning only about 1813 (see Hoskins 1963, p. 175).

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