NOTES

THE CENTRAL STARS OF PLANETARY NEBULAE OF LOW SURFACE BRIGHTNESS

Many nebulae of low surface brightness have been found on the Palomar Survey plates, by Abell (1955), and on the prints, by Vorontsov-Velyaminov (1962). Abell is obtaining *UBV* photometry, and O'Dell (1963) has published luminosities, temperatures, and radii for the central stars from the recombination theory for Hβ. Through the kindness of Dr. Abell we obtained some years ago finding charts and preliminary photoelectric data in order to observe the spectra of the central stars at Palomar. Prime-focus dispersions of 180 and 85 Å/mm were used; widened spectra show emission lines from

TABLE 1

PROPERTIES OF THE CENTRAL STARS AND PLANETARY NEBULAE

Description	Type	M_V	Stellar Absorption and Emission Lines	Emission Lines in Nebulae
A7.	sd Ok	+6	He II, H broad	.
A15	sd Op	+4	H, He II, He I very weak. He II emission may be either from star or nebula	?
A30	O5fep	+2	H, C IV broad and weak. O VI emission very strong	[O III], [Ne III]
A31 = VV20	sd O6	+6	He II strong, H very broad and shallow	[O III]
A33 = VV22	sd Op	+5	H very broad and shallow. He II weak	[O III]
A36 = VV25	sd O7	+4	H, He II strong. Like +28°4211 but hotter	. .
A39 . . .	sd O	+6	H weak, very broad. No He II	[O III]?
A43 = VV31	O7fk	+1	He II, C IV, H strong and sharp	[O III]
A46 = VV34	O9k	+2	H strong sharp; He II weak	[O III]
A51 = VV38	sd O8k	+4	H broad; He II, C IV weak	[O III]
A65	Opk		No lines visible; masked by nebular emission	H, [O III], [Ne III]
A74 . .	sd Op or DC	+7?	No lines visible	. .
A78 = VV64	O5fek	+1	H weak and broad. Variable C IV Of lines, strong λ 5801–12 emission. O VI emission stronger than He II	[O III], [Ne V]
NGC 246	sd Ofe	+3	C IV, O V absorption strong; H weak and broad O VI emission weak	

the nebula only weakly, because of their extremely low surface brightness. Since these stars represent a short-lived evolutionary stage which at least some hot stars pass through before the white-dwarf stage, their spectroscopic properties are of interest.

In Table 1 we give the Abell designation, an estimated spectral type, a luminosity estimated from the H or He II stark-broadening line widths (with allowance for the very high temperature), and remarks on details of the spectra. The last column gives the emission lines noted in the nebula. The Abell designation is not that of his 1955 paper, but an unpublished one also quoted by O'Dell (his Table 2). The spectral types are very rough, since the stars have so low an absolute luminosity that the normal criteria for main-sequence O stars are irrelevant. They always have very weak lines, unless they are of the higher luminosity Of type. Some are so hot and weak-lined that no decimal subdivisions can be given. The symbol "Of" is used for stars with combined emission and absorption lines, usually of C IV; the symbol of "Ofe" is used if the emission is strong. An interstellar calcium line is indicated by "*k*." The luminosities estimated from such spectra are, of course, very rough and represent an interpolation between horizontal-branch early B or O stars and the hottest white dwarfs. The notation "sd," or subdwarf, is added for stars of spectroscopically apparent low luminosity. In addition, we list our results for the nucleus of NGC 246, a better known object, whose luminosity was first estimated by Minkowski and Baum (1960), from a G-dwarf companion. In Figure 1 we also plot its luminosity as given by O'Dell (1963). The luminosity of +28°4211 can be estimated from the interstellar K-line (Greenstein 1952) and from its membership

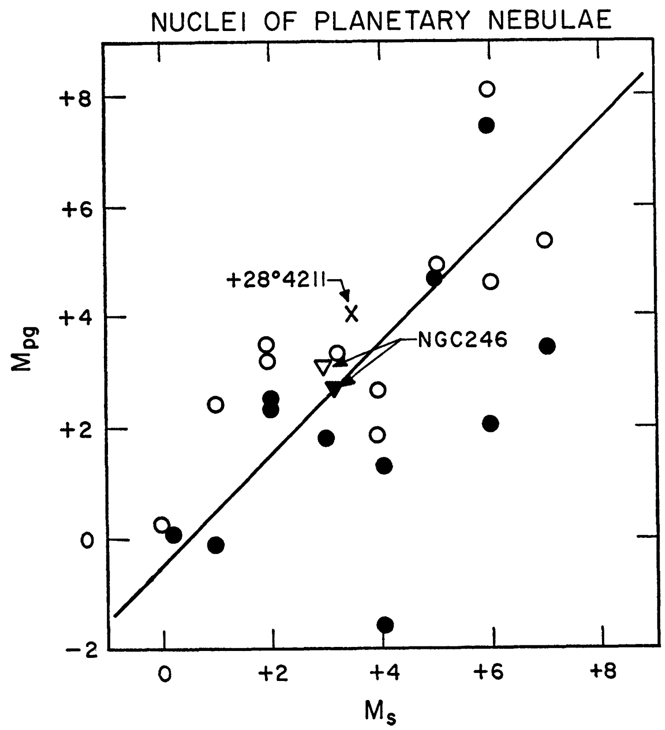

FIG. 1.—(ordinate) The absolute magnitudes M_{pg} derived from the nebular emission by O'Dell (*filled circles*) and by Abell (*open circles*) are compared with the spectroscopic estimates of M_s from this paper. The M_{pg}'s for NCG 246 are plotted as triangles, filled (O'Dell) and open (Baum and Minkowski). The cross is the star +28°4211, which resembles a planetary nucleus.

in the γ Leonis moving group (Eggen 1959). It is almost a spectroscopic twin of Abell 36, and is plotted as another reference point, even though it does not now have a planetary nebula. The lifetime of a planetary nebula may be somewhat shorter than that of such stars, or possibly the stars have several outbursts of gas.

Figure 1 shows a comparison of the estimated luminosities, from O'Dell, and from this investigation, as well as some preliminary estimates by Abell, which he kindly permits us to quote. While the scatter is large, there is, in general, a fair correlation. The line, of unit slope, drawn through the scatter diagram shows a small zero-point error (−0.5 mag.), i.e., a tendency to estimate the luminosities too low, spectroscopically, for the least luminous stars.

Figure 2 gives reproductions of the spectra of the very hot objects Abell 30, and two

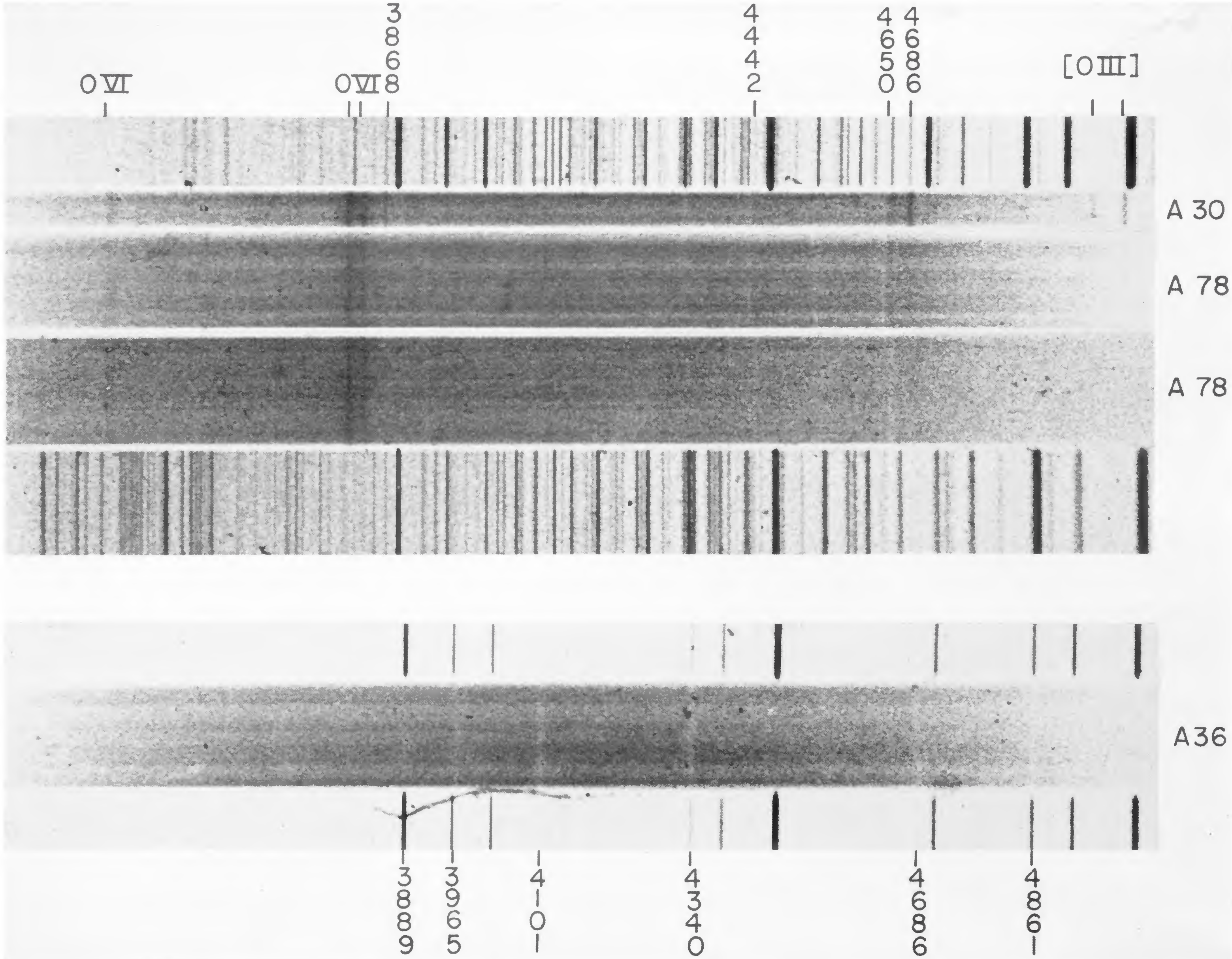

FIG. 2.—Spectra of the central stars of Abell 30 and two of Abell 78. The latter has a variable spectrum. There is no appreciable emission from the nebula except very weak [Ne v]. The ultraviolet stellar O VI has very high excitation; the λλ 3811–34 doublet has broad emission wings. Abell 36 has no emission lines, and resembles a hot subdwarf. The pressure-broadening is large, with H8 the last Balmer line visible.

of Abell 78, showing clearly the variations in the Of lines. The original plates are 180 Å/mm; those of Abell 78 were widened to 0.8 mm. Only a limited region of each plate is in focus.

The Zanstra temperatures given by O'Dell are minimum values for these stars, ranging from 70000° K for Abell 31 (type O5) to 23000° K for Abell 36 (type O7). No nebula showed [O II], i.e., all are quite hot. But the two stars which we believe to be the hottest, Abell 30 and 78, have the low minimum Zanstra temperatures of 24000° and 19000° K, according to O'Dell. The associated nebulae have the highest ionization level (e.g., [Ne V] present), and so the O'Dell temperatures are here very deceptive. The complex and variable C IV emission and absorption lines and especially O VI are extremely strong in these stars, with excitations of 58 and 82 eV. Near the [Ne V] λ 3426 line there is another line at λ 3434 in Abell 30 and 78, which is almost certainly λ 3433.69 of O VI. The excitation is 128 eV and an ionization potential of 138 eV is required to produce O^{6+}. The Of absorption line of C IV at λ 4442 arises from a 5^2P^0 level, which communicates with a 2^2S ground state. Thus, temperatures in a stellar chromosphere are indicated of at least 60 eV, and probably 130 eV. The *UBV* colors indicate very high temperatures (e.g., -0.33^m, -1.27^m for Abell 36) approaching the limiting value for infinite temperature. The emission lines visible are, in general, of the level of excitation of those seen in the rocket-ultraviolet solar spectrum. These planetary nuclei have large bolometric corrections, so that the radii will lie between 0.1 and 0.01 $R_\odot$. The spectroscopic features are consistent with a hot, high-pressure atmosphere and chromosphere, with an instability leading to some continued mass loss. The O VI emission doublet is clearly blended, although 23 Å in separation, and the total width of the wings of the emission is nearly 100 Å. A half-width of nearly 20 Å corresponds to 1500 km/sec. Too large for thermal motion, the line widths could be a measure of the initial velocity of ejection, or conceivably the result of electron scattering. Although they were discovered on Hα 48-inch Schmidt plates, a peculiar fact is the weakness of the hydrogen emission in the nebulae, visible only in Abell 65. All other elements seen in these stars and nebulae are alpha-particle nuclei; several plates of Abell 78 fail to show [N II] or even Hα. The Of characteristics are strongest in C IV and absent in nitrogen. There is some possibility, therefore, that the stars belong to a carbon sequence, are somewhat hydrogen-deficient, and could be relics of the interiors of red giants.

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