

CASSEGRAIN IMAGE-TUBE SCANNER OBSERVATIONS OF THE CENTRAL STARS OF PLANETARY NEBULAE*

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ABSTRACT

Cassegrain image-tube scanner observations obtained with the Lick Observatory 305 cm telescope are presented for the central stars of seven planetary nebulae. Absolute fluxes of stellar emission features and equivalent widths of absorption lines are determined for the blue spectral region (3770–5000 Å) of these stars. The central stars of NGC 7094, Cn 3-1, and NGC 6857 have not been observed previously. NGC 7094 has an O-type central star. Cn 3-1 has a central star with W-R-Of features. The central star of NGC 6857 probably has a continuous spectrum. The equivalent widths of the He II absorption lines in the Ofp central stars (NGC 6826 and IC 4593) are found to be comparable to He II equivalent widths in the six Population I O stars which show He II, C III, and N III in emission.

Subject headings: nebulae: planetary — spectrophotometry — stars: early-type

I. INTRODUCTION

The central stars of planetary nebulae are difficult to observe, and the observations are difficult to interpret because the stars are faint and because emission lines from the nebular shell often interfere with absorption and emission features from the central star. Nevertheless, interpretation of the various types of central stars is necessary to understand the evolution of planetaries. The purpose of this study is to present accurate photoelectric scanner observations in the blue spectral region for a small number of central stars. These data can be used in conjunction with other observational information and model atmospheres to gain information about the physical parameters and stage of evolution of such stars.

II. OBSERVATIONS

The observations were obtained with the image-tube scanner at the Cassegrain focus of the Lick Observatory 3 m reflector during 1974 June and July.

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The objects and the parameters of the observing program are summarized in Table 1. The standard stars observed each night were BD +33°2642 and BD +28°4211. The data were reduced to absolute flux units using the Scanner Data Reduction System programs on the PDP-8 computer at Lick Observatory (Robinson and Wampler 1972; Stone 1974; Miller, Robinson, and Wampler 1976). The intensities of the emission features in the central stars and the equivalent widths of absorption features were also obtained with computer reduction programs available at Lick Observatory. In Figures 1–7, spectra of the program objects are shown. The central stars will be discussed individually in § III.

III. THE CENTRAL STARS

NGC 6826.—The central star of NGC 6826 is classified as type O6fp (Smith and Aller 1969). The 56 Å mm⁻¹ scanner spectrum of this object is shown in Figure 1. The features of particular interest in Ofp central stars are the He II P α emission at λ 4686; the N III emission at λ 4634, 4641–4642; the C III

TABLE 1
THE OBSERVING PROGRAM

Object	Date (1974)	Dispersion (Å mm ⁻¹)	Wavelengths (Å)	Duration (Min)
NGC 6543	23/24 July	78	3775–4900	8
NGC 6826	29/30 June	56	3950–4840	8
NGC 6826	30 June/1 July	56	3955–4840	16
NGC 6857	29/30 June	78	3770–5000	16
NGC 7008	30 June/1 July	78	3770–5000	24
NGC 7094	30 June/1 July	78	3770–5000	16
NGC 7094	22/23 July	78	3780–5005	16
IC 4593	23/24 July	78	3775–4900	16
Cn 3-1	23/24 July	78	3775–4900	32

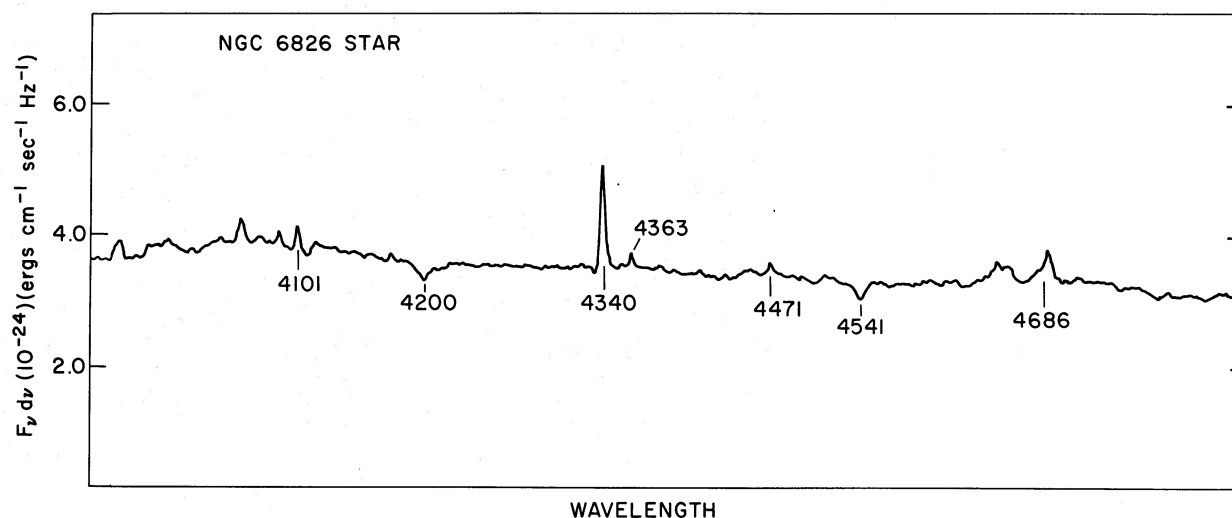


FIG. 1.—The central star of NGC 6826

emission at $\lambda\lambda 4647, 4650\text{--}4651$; and the absorption lines of the He II Pfund series at $\lambda\lambda 4200, 4541$. Because of the low resolution of the scanner, the C III and N III emission features are blended, and individual line intensities cannot be determined in the region $\lambda\lambda 4630\text{--}4650$. The total flux of the $\lambda 4686$ emission feature is measured to be $8.5 \pm 0.8 \times 10^{-13}$ ergs $\text{cm}^{-2} \text{s}^{-1}$. The equivalent widths of the $\lambda 4200$ and $\lambda 4541$ absorption lines are given in Table 2. The equivalent widths measured in the present investigation are slightly larger than those measured by other authors. Further discussion of the He II equivalent widths is presented in § IV.

IC 4593.—The central star of IC 4593 is classified as type O7fp (Smith and Aller 1969). The 78 Å mm^{-1} scanner spectrum of the star is presented in Figure 2. The prominent features in the spectrum are the same

as those mentioned for the central star of NGC 6826. The flux of the $\lambda 4686$ emission is $1.8 \pm 0.2 \times 10^{-13}$ ergs $\text{cm}^{-2} \text{s}^{-1}$. Aller and Wilson's (1954) spectroscopic study indicated that $\lambda 4686$ in the central star of IC 4593 was comparable in intensity to the C III and N III emission features. In the present study, the strength of $\lambda 4686$ is much less than anything in the blend of features from $\lambda 4630$ to $\lambda 4650$. This may be an indication of variability in the central star of IC 4593. Variations in the intensities of spectral features have been reported for other central stars (Smith and Aller 1969), but this is the first evidence for variability in this particular star. The equivalent widths of the He II absorption lines are given in Table 2.

NGC 6543.—This planetary has a W-R-Of central star. N V $\lambda\lambda 4603, 4619$, C IV $\lambda\lambda 4646, 4658$, and He II $\lambda 4686$ are seen in emission. No absorption lines are

TABLE 2
EQUIVALENT WIDTHS* OF He II ABSORPTION LINES IN Ofp AND O-ABSORPTION CENTRAL STARS AND
POPULATION I OF STARS WITH C III AND N III EMISSION

OBJECT	4200 Å					4541 Å				
	PW	A	AW	H ₁	H ₂	PW	A	AW	H ₁	H ₂
NGC 6826.....	0.79	0.51	...	0.37	0.57	0.88	0.80	...	0.67	0.74
IC 4593.....	0.61	0.45	0.52	...	...	0.75	0.76	0.53		
NGC 7094.....	0.95	...	...	...	...	1.20				
NGC 7008.....	0.63	...	...	...	...	1.00				
CA						CA				
HD 108 (O7 If).....	...					0.89				
HD 14947 (O5.5f).....	0.56					0.72				
HD 15570 (O4f).....	0.50					0.76				
HD 18629 (O5f).....	0.63					...				
HD 16691 (O5f).....	0.52					0.87				
HD 152408 (O8 If).....	0.34					0.65				

NOTE.—PW = present work. A = Aller 1948. AW = Aller and Wilson 1954. H₁H₂ = Heap 1970. CA = Conti and Alschuler 1971 and Conti 1973.

* In angstroms.

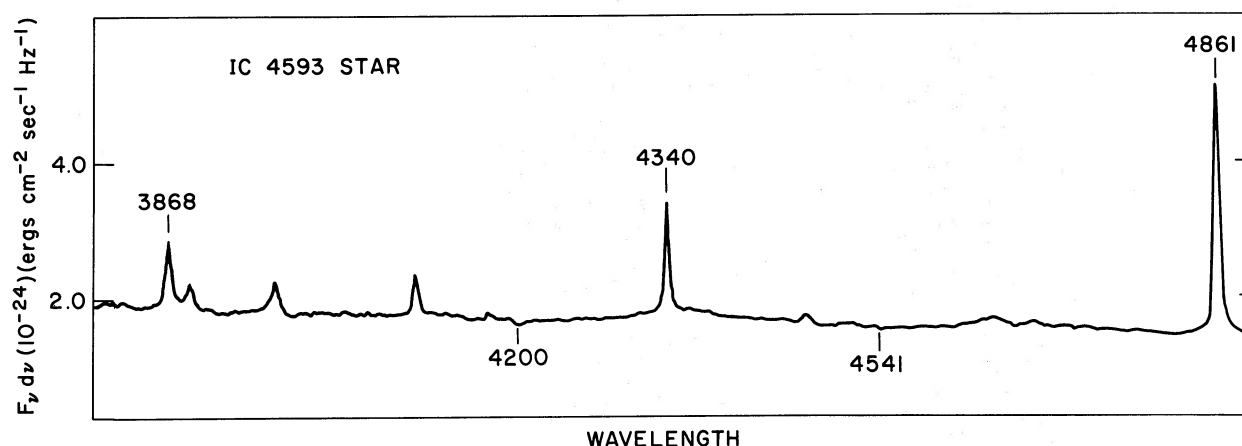


FIG. 2.—The central star of IC 4593

seen in the spectra taken with the scanner, although absorption lines have been reported by other investigators (Aller 1967). The spectral features are reported to be variable (Aller 1967). The spectrum of this central star is shown in Figure 3. The flux of He II $\lambda 4686$ is $2.7 \pm 0.3 \times 10^{-12}$ ergs $\text{cm}^{-2} \text{s}^{-1}$.

Cn 3-1.—The spectrum of the central star of Cn 3-1 is shown in Figure 4. This star shows some W-R-Of characteristics. N v and C iv features are present, but He II is weak or absent. The intensities of the nebular emission lines are overwhelming compared to the continuum and emission features from the central star. The nebular emission lines will be discussed elsewhere (Lutz 1976).

NGC 7094.—The spectrum of the central star of NGC 7094 is shown in Figure 5. No emission features from the nebula are seen in this spectrum because of the instrumental properties of the Cassegrain image-tube scanner. The scanner has two slots which are 35" apart. In most cases the program object is centered in one slot while the other slot monitors the sky background. The sky background is subtracted from the spectrum of the object. NGC 7094 is a large

planetary nebula, so that when the central star is set on one slot of the scanner, the nebular radiation passes through the other slot. Consequently, much of the nebular emission was subtracted out of the observations of the central star spectrum. It is not possible to determine whether this subtraction is complete, incomplete, or overdone. Thus, while hydrogen lines appear in absorption in the scanner spectrum of the central star of NGC 7094, it would not be productive to measure their equivalent widths. However, the nebular shell does not exhibit emission in He II, so the equivalent widths of the absorption lines of He II $\lambda 4200$ and $\lambda 4541$ were measured and are given in Table 2. There is also evidence of absorption at wavelengths characteristic of He I, He II, and C III. An image-tube spectrogram ($120 \text{ \AA mm}^{-1}$) taken of NGC 7094's central star with the Carnegie image-tube spectrograph on the 210 cm telescope at Kitt Peak National Observatory confirms the presence of absorption features which are found in O-type stars with no emission features. This type of spectrum has not been emphasized as a distinct category among the central stars of planetary nebulae (Smith and Aller

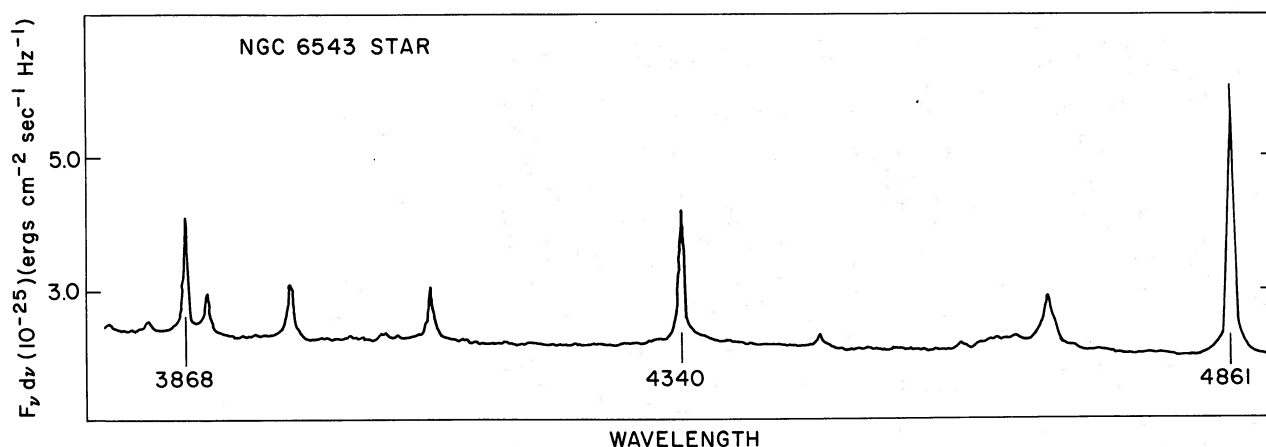


FIG. 3.—The central star of NGC 6543

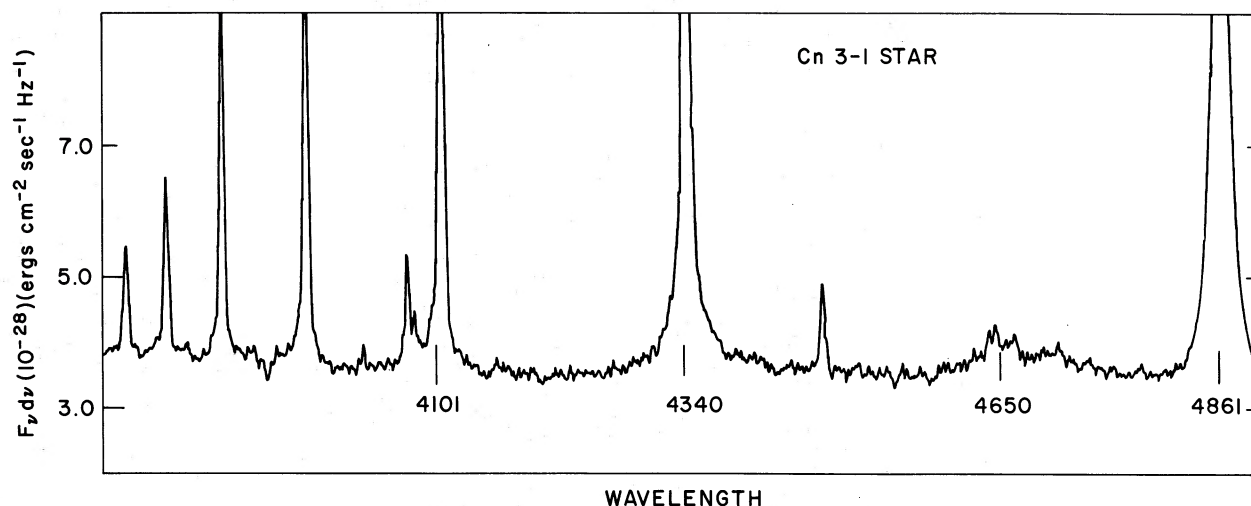


FIG. 4.—The central star of Cn 3-1

1969), although Aller (1967) noted the presence of several O-type absorption spectra in a general spectroscopic survey of central stars.

NGC 7008.—The central star of NGC 7008 was observed previously by Aller (1967), who noted that the star shows absorption lines. The spectrum of the central star is shown in Figure 6. NGC 7008 has a radius greater than $35''$, so the comments on NGC 7094 concerning the subtraction of nebular emission from the central star spectrum also apply to the observations of the central star of NGC 7008. No emission features from the central star are seen in the spectrum. There are absorption lines which might tentatively be identified with helium, carbon, and nitrogen. Equivalent widths are given in Table 2 for $\lambda 4200$ and $\lambda 4541$, the two most prominent absorption lines. The central star of NGC 7008 is probably an O-type star.

NGC 6857.—This is another large planetary nebula, so the nebular emission has been at least partially

subtracted from the central star observations. The spectrum of the central star is shown in Figure 7. If the Cahn and Kaler (1971) extinction for NGC 6857 is used to take the effects of interstellar absorption out of the observations, then the continuum energy distribution of the central star resembles that of a hot blackbody, as expected. No definite emission or absorption features are seen from the central star. It is most likely that the central star has a continuous spectrum.

IV. THE He II ABSORPTION LINES

The He II equivalent widths given in Table 2 can be compared with similar data for Population I O stars (Conti and Alschuler 1971; Conti 1973). In particular, there is a small group of O stars which have N III, C III, and He II $P\alpha$ in emission and the He II Pfund lines in absorption. These stars would seem to be the most suitable for comparison with the central stars of

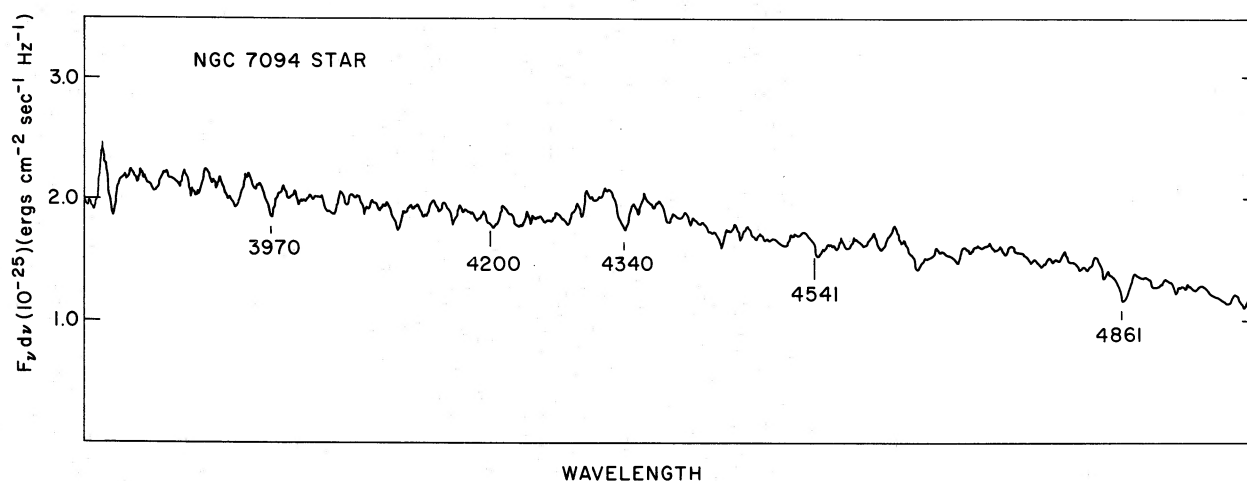


FIG. 5.—The central star of NGC 7094

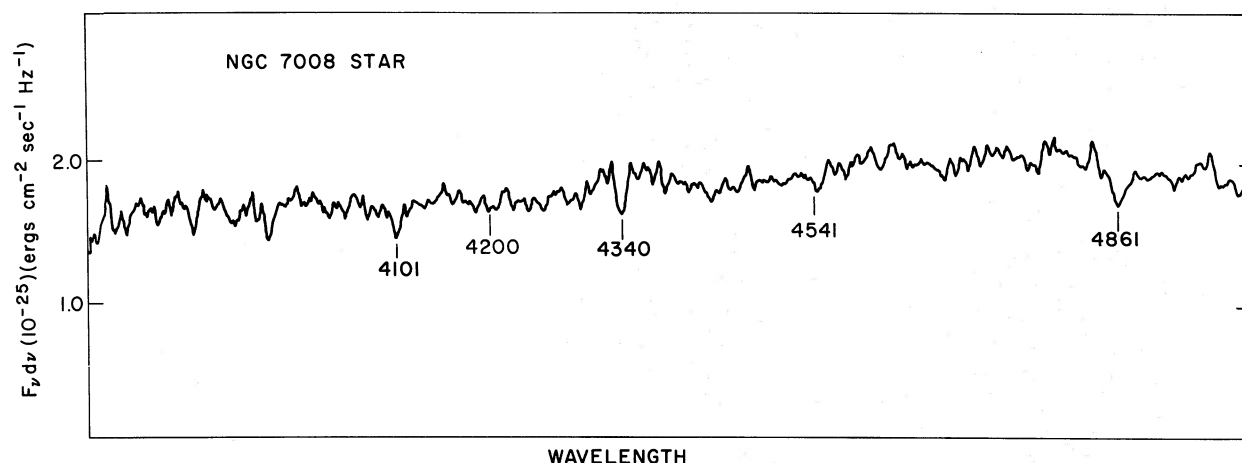


FIG. 6.—The central star of NGC 7008

NGC 6826 and IC 4593. The HD numbers, spectral types, and He II $\lambda\lambda 4200, 4541$ equivalent widths for these stars are included in Table 2. The data for the Population I stars in Table 2 are all from Conti and Alschuler (1971) and Conti (1973). There is considerable overlap between the He II equivalent widths in the central stars and in the comparable group of Population I O stars. If spectra of the stars themselves (no nebular lines) were the only observational evidence, it would be difficult to distinguish between the Population I O stars in Table 2 and the Ofp central stars of planetary nebulae.

At the present time it is not possible to compare the observed He II equivalent widths with model atmosphere calculations. Kunasz, Hummer, and Mihalas (1975) have generated spherical non-LTE atmospheric models for $0.6 M_{\odot}$ and $1.2 M_{\odot}$ stars, but so far equivalent widths for absorption lines in these

low mass stars are not available. Calculations of He II equivalent widths in extended stellar atmospheres for stars with a wide range of masses would be of great value for determining the physical properties of individual O-type central stars.

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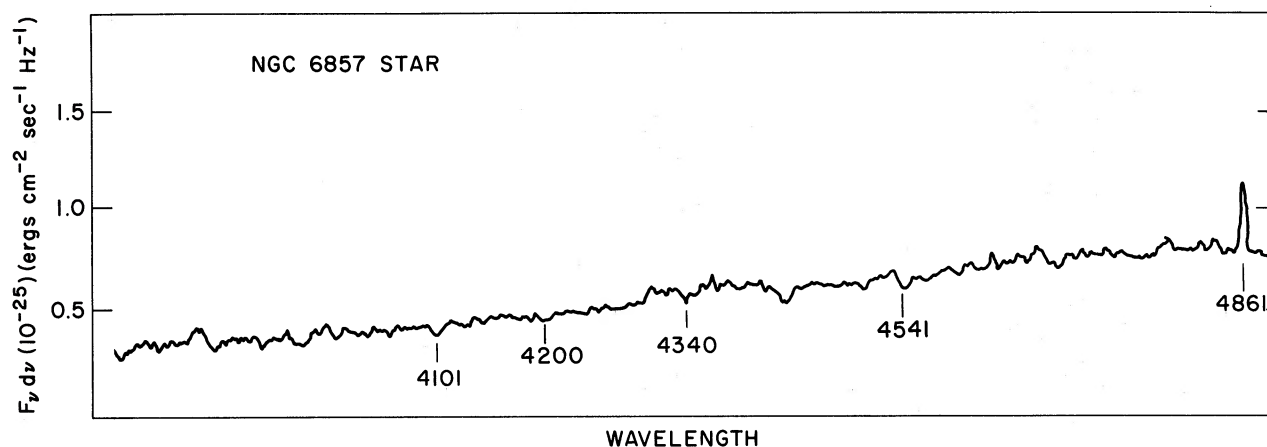


FIG. 7.—The central star of NGC 6857

REFERENCES

- Aller, L. H. 1948, *Ap. J.*, **108**, 464.
———. 1967, in *IAU Symposium No. 34, Planetary Nebulae*,
ed. D. E. Osterbrock and C. R. O'Dell (New York:
Springer-Verlag), p. 339.
Aller, L. H., and Wilson, O. C. 1954, *Ap. J.*, **119**, 243.
Cahn, J. H., and Kaler, J. B. 1971, *Ap. J. Suppl.*, **22**, 319.
Conti, P. S. 1973, *Ap. J.*, **179**, 161.
Conti, P. S., and Alschuler, W. R. 1971, *Ap. J.*, **170**, 325.
Heap, S. R. 1970, Ph.D. thesis, University of California at
Los Angeles.
Kunasz, P. B., Hummer, D. G., and Mihalas, D. 1975,
Ap. J., **202**, 92.
Lutz, J. H. 1976, *Pub. A.S.P.*, submitted.
Miller, J. S., Robinson, L., and Wampler, E. J. 1976, *Advances
in Electronics and Electron Physics*, Vol. **40** (New York:
Academic Press).
Robinson, L. B., and Wampler, E. J. 1972, *Pub. A.S.P.*,
84, 161.
Smith, L. F., and Aller, L. H. 1969, *Ap. J.*, **157**, 1245.
Stone, R. P. S. 1974, *Ap. J.*, **193**, 135.

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