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THE PECULIAR OBJECT He 2–467

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ABSTRACT

He 2–467 has been classified as a planetary nebula. However, the spectrum of this object shows emission lines superposed on the absorption spectrum of a G-type star. Image tube spectrograph and scanner observations of the emission and absorption features are presented. The emission spectrum is unusual in that no forbidden lines are seen, and the He I singlet to triplet ratios do not agree with recombination theory.

Subject headings: nebulae: planetary — stars: emission-line

I. INTRODUCTION

He 2–467 (designated 63° − 12°1 in Perek and Kohoutek 1967) was discovered in the course of an Hα survey by Henize (1967). It has a stellar appearance on a plate taken with the Naval Observatory's 102 cm reflector (Henize 1967). Henize classified this object in his category 7 (no confirming criteria; Hα intensity > 1 on a T = trace to 5 = very strong scale; no continuum). His study suggested that objects in category 7 have a 0.58 to 0.98 probability of truly being planetary nebulae.

This object was observed by Shao and Liller (1974) in a photoelectric survey of central stars of planetary nebulae. The colors found are peculiar in that they are not characteristic of a hot star ($V = 14.10$, $B - V = +0.41$, $U - B = -0.23$). Allen (1974) included He 2–467 in an infrared survey of emission-line stars, and he classified it as a compact planetary whose infrared spectrum resembles that of a late-type star.

The apparently peculiar nature of He 2–467 is verified by the present work. Spectroscopic observations of He 2–467 indicate the presence of an emission spectrum with lines of H, He I, He II, and C II superposed on a stellar spectrum with absorption features and continuum which are characteristic of a G star. In the following sections we will discuss our observations and possible interpretations of our data.

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II. OBSERVATIONS

Two spectrograms of He 2–467 were obtained with the image tube spectrograph on the Steward Observatory's 229 cm telescope. He 2–467 was also observed with the Cassegrain image tube scanner on the 305 cm telescope at the Lick Observatory. The observations are summarized in Table 1. The standard stars observed with the scanner were BD +33°2642 and BD +28°4211 for the blue region, and Feige 15 for the red region, where we adopted the fluxes measured by Stone (1974). The internal errors for the line intensities are approximately ±10 percent for the strongest lines and ±25 percent or more for the weaker lines.

The blue and red image tube scanner spectra of

TABLE 1
OBSERVATIONS OF He 2–467

Telescope (cm)	Date	Dispersion (Å mm^{-1})	λ Range (Å)	Duration (min)
229..........	1974 May 9/10	120	3700–4900	11
229..........	1974 May 10/11	120	5500–7000	12
305..........	1974 July 22/23	78	3700–4900	32
305..........	1974 September 11/12	154	4600–6700	8

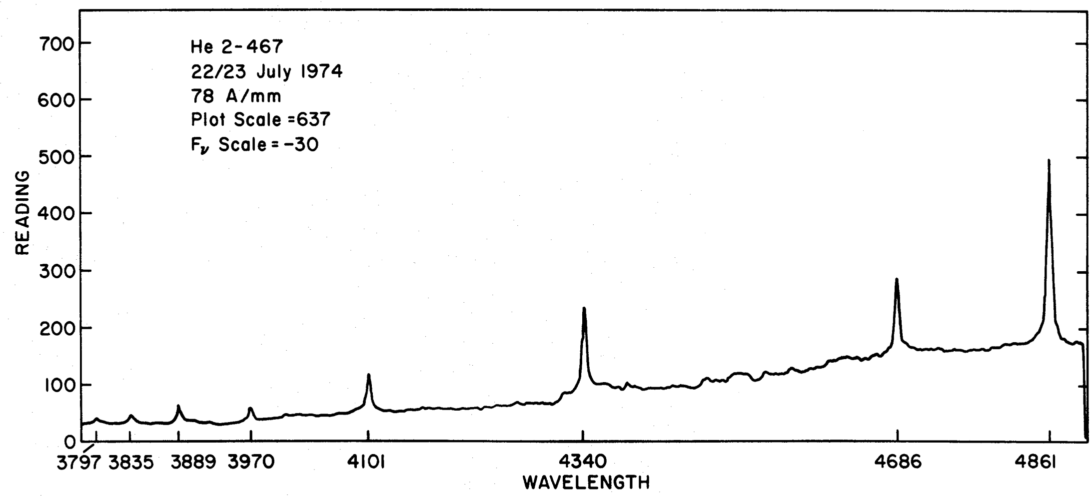

FIG. 1.—Scanner observations of He 2–467 in the blue

He 2–467 are shown in Figures 1 and 2, respectively. The readings of the figures can be translated into intensity units via

$$F_\nu\,(\text{ergs cm}^{-2}\,\text{s}^{-1}) = \text{READING} \times \text{PLOT SCALE} \times 10^{F_\nu \text{Scale}}\,.$$

The absolute flux at Hβ is 2.18×10^{-13} ergs $\text{cm}^{-2}\,\text{s}^{-1}$. The relative emission-line strengths on the scale I (Hβ) = 100 are presented in Table 2.

Figure 3 shows the absorption features in the blue scanner spectrum of He 2–467. These are found at the following wavelengths (Å): 3933, 3968, 4226, 4300 (G band), 4383, 4462 (blend of features), 4532 (blend of features). Few absorption features are well defined because of the low resolution of the scanner. The blue image tube spectrogram shows the same absorption features as the scanner data. The absorption features are characteristic of a star of spectral type G; no luminosity classification is possible. Note from the figures that the continuum increases and levels off in the red region, as expected for a late-type star.

III. DISCUSSION OF THE EMISSION-LINE SPECTRUM

He 2–467 is clearly an unusual object. It exhibits a high-excitation emission spectrum (note the presence of λ4686 of He II), yet the absorption features in the spectrum and the behavior of the continuum in the red indicate that a late-type star is present.

The lack of forbidden lines in the emission spectrum indicates that this object must be very dense ($N_e \approx 10^8\,\text{cm}^{-3}$ or greater). A striking characteristic of the spectrum is that the He I singlets are stronger than the triplets; the ratio is just the opposite of what one finds

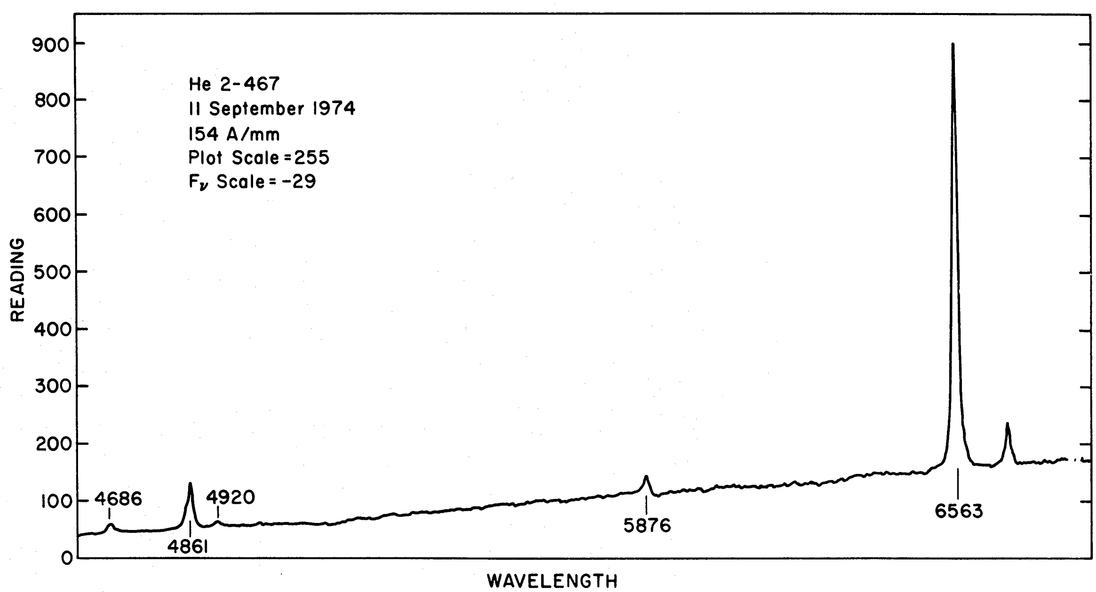

FIG. 2.—Scanner observations of He 2–467 in the red

TABLE 2

Emission Lines in He 2–467

Wavelength (Å)	Identification	Intensity $[I(H\beta) = 100]$
3797..........	H10	3.8
3835..........	H9	5.1
3889..........	H8 + He I	10.8
3970..........	H7	7.3
4010..........	He I	2.1
4101..........	Hδ	21.7
4267..........	C II	1.4
4340..........	Hγ	43.8
4387..........	He I	2.8
4686..........	He II	32.2
4861..........	Hβ	100.0
4921..........	He I	11.2
5015..........	He I	3.2
5876..........	He I	18.2
6563..........	Hα	435.3
6678..........	He I	40.2

in the spectra of planetary nebulae in general and from recombination theory (Brocklehurst 1972). Clearly, effects other than recombination are important.

In order to make quantitative evaluations of the spectrum, we must first estimate the degree of interstellar extinction. The logarithmic extinction at Hβ, c, can as a rule be determined by first adopting a reddening function and then comparing the observed hydrogen line intensities with those predicted by recombination theory. However, the anomalous He I singlet-to-triplet ratio indicates that strict recombination theory might not be applicable and that self-absorption and other high-density effects may be important. We have tried to determine whether self-absorption is significant by placing our Hα, Hβ, Hγ, and Hδ data on the plots of log (Hα/Hβ) versus log (Hγ/Hβ) and log (Hγ/Hβ) versus log (Hδ/Hγ) presented by Cox and Matthews (1969). The Hα, Hβ, Hγ data indicate possible self-absorption, but the Hβ, Hα, Hδ plot falls below the allowed locus. The points can all be brought to the reddening line if we assume that we have underestimated the intensity of Hγ by 10 percent, which is within the estimated errors of observation.

For the sake of further argument, we assume that recombination theory applies to the hydrogen emission lines. We adopt the Whitford (1958) reddening function and, because of the high density, Clarke's (1965) theoretical intensities for the degenerate case. From Hα/Hβ, Hγ/Hβ, and Hδ/Hβ we get $c = 0.62$, 0.46, and 0.70, respectively. With a weighting of 3:1:2, $\bar{c} = 0.62$. We are probably safe in saying that $c = 0.62$ or less, assuming effects other than recombination may be present.

If we adopt $c = 0.62$, we find that, within ± 25 percent, the He I singlet line decrement (λλ6678, 4921, 5387) agrees with that predicted by recombination theory (Brocklehurst 1972), but that the $I(6678)/I(H\beta)$ ratio is much too strong. The observed ratio (at $T_e = 10^4$ K) would require that He/H ≈ 0.6 to satisfy recombination theory. The one triplet line (λ5876) is consistent with He/H ≈ 0.1, but, by recombination theory, $I(\lambda 4471)$ should be about 4. The λ4471 line should be observed, but it is not. A realistic theoretical analysis of the emission-line spectrum of He 2–467 will be a difficult task.

IV. POSSIBLE BINARY NATURE OF He 2–467

Since an ordinary G star is not hot enough to ionize a planetary nebula, we consider the possibility that He 2–467 has an invisible but hot companion which is responsible for the emission-line spectrum. This supposition would be consistent with the results of investigations of the AO central stars of NGC 1514 (Kohoutek 1967; Kohoutek and Hekela 1967;

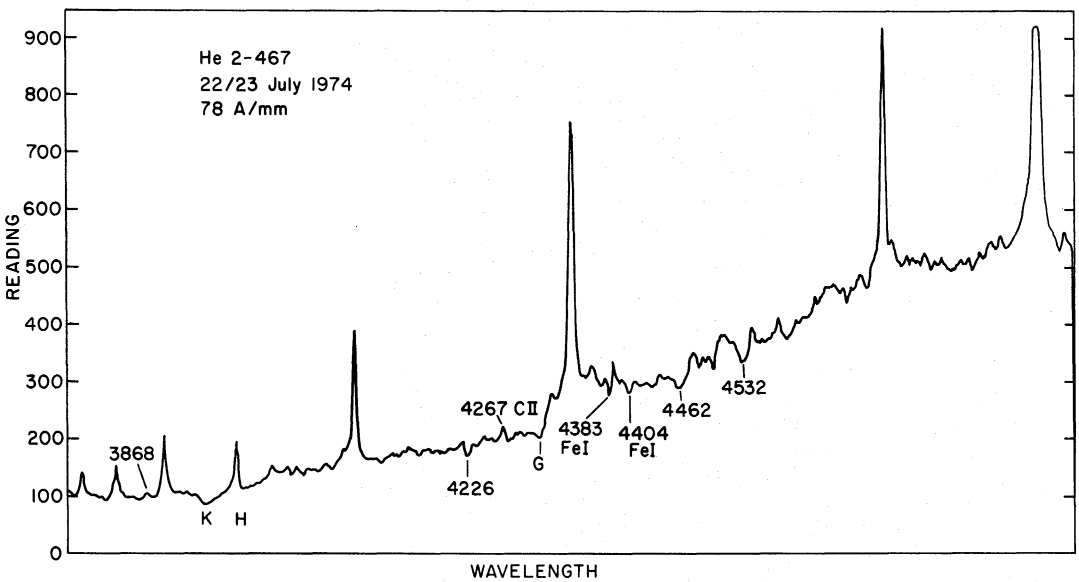

FIG. 3.—The absorption features of He 2–467

Greenstein 1972) and NGC 2346 (Kohoutek and Senkbeil 1973). However, it should be noted that Hel–5 (FG Sge) and Ml–2 (O'Dell 1966) are planetary nebulae with G-type central stars, and, despite extensive investigations, no evidence has been found that these cool central stars have faint, hot companions.

We have classified the central star of He 2–467 as a G star because of the presence of the G band and Ca I λ4226. However, the hydrogen absorption lines are completely filled in by H I emission, and the image tube spectrograms are only 0.3 mm widened. Thus, the spectral type cannot be precisely determined; our best estimate is that it is near G, but it could be anywhere from F5 to K0.

A possible weak absorption feature at about λ4173 appears on one of two scanner tracings, and it is not seen on the image tube spectrogram. If this feature is real, it may be a blend of λλ4172, 4175, in which case the G star would be above the main sequence.

We adopted the *UBV* data for He 2–467 from Shao and Liller (1974) and the intrinsic colors for ordinary stars from FitzGerald (1970). Using these, we found that an F6 V + O combination in a binary system would be consistent with the observed colors. Adopting $M_v = +3.5$ for the F6 V star (Blaauw 1963) would give $M_v = +6.5$ for the O star, which is rather faint. However, the computations which led to the F6 V + O combination were based on $E(B - V) = 0.0$. If He 2–467 is reddened, as seems to be the case from the results of § III, then the spectral type of the visible star comes out earlier than F6, which contradicts the appearance of the spectrum.

If the visible companion is indeed cooler than F6 V, the "hot" companion would have to be a B star. A B star would be too cool to produce the observed emission-line spectrum. Thus, if the visible central star of He 2–467 is indeed a normal G star, then the existence of a companion star hot enough to ionize the nebula is not consistent with the observed colors. It should be noted that if the G star in He 2–467 is a pathological star with weird colors, then the arguments given here about the binary nature of this object would not apply, since our computations are based on colors for normal stars.

V. SUMMARY

He 2–467 is peculiar in that it has a high-excitation emission-line spectrum superposed on the spectrum of a G star. The observed He I spectrum of this object does not agree well with the predictions of recombination theory. At present it is not clear whether or not He 2–467 should be grouped with objects like M1–2 and He1–5 (FG Sge) which exhibit forbidden lines and G-type absorption spectra. He 2–467 may be more like BD +67°922 = AG Dra (Janssen and Vyssotsky 1943; Wilson 1943, 1945; Roman 1953), a ninth mag variable star of spectral type G which has emission lines of H, He I, and He II.

If the central star of He 2–467 is a giant, the possibility exists that this is an object contracting onto the main sequence. If the G star is in a T Tauri phase, it may be possible to explain the emission-line spectrum through some form of mechanical energy mechanism.

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