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He 3-519: A PECULIAR POST-LBV, PRE-WN STAR?

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ABSTRACT

We report *IUE* and ground-based data indicating that the star He 3-519 has a distance of roughly 8 kpc and an absolute bolometric magnitude of about −11, comparable to AG Car. Its luminosity, spectrum, and large, massive circumstellar shell indicate that this may be a post-LBV object which has not yet become a full-fledged WN star. One notable peculiarity of He 3-519 is its prominent Fe III (?) λ3008 emission; the reason why this feature is so bright in this star's dense envelope or wind, but not in other related stars, is not yet clear.

Subject headings: stars: individual (He 3-519) — supergiants — ultraviolet: stars

1. INTRODUCTION

Among the handful of very luminous blue variable (LBV) and related Of/WN stars known in our Galaxy, several are scattered along the Carina spiral arm at distances beyond 2.5 kpc: Eta Car, AG Car, HR Car, and He 3-519 (see, e.g., Humphreys 1989). The last of these, He 3-519, has received little attention so far. Hoffleit (1953) discovered that it is surrounded by a shell nebula, and Henize (1976) noted spectroscopic similarities to AG Car.[5] Stahl (1986, 1987) has briefly commented on He 3-519 from a modern point of view, including its Ofpe/WN9-like nature, and has presented a CCD emission-line image of its circumstellar shell.

From Stahl's discussion it is clear that He 3-519 may be extremely luminous and highly reddened. In order to make a more secure estimate of the reddening and extinction, and to learn more about its physical nature, we obtained ultraviolet spectral data on He 3-519 in 1990 and 1991, using the *IUE*. To assess the reddening-distance relation toward He 3-519 and AG Car (which are only half a degree apart in the sky), we have also observed the *UBV* magnitudes and spectra of several stars close to the line of sight. We find that He 3-519 is quite distant and is roughly as luminous as AG Car.

We also find some unique spectral peculiarities in He 3-519. The emission lines from its wind or envelope are relatively brighter than in AG Car and similar objects, and our *IUE* data show at least one conspicuous UV feature which may be unmatched in any other known spectrum—with the possible exception of some observations of P Cygni more than 50 years ago!

In this paper we discuss the problem of He 3-519 in light of our *IUE* and ground-based data and Stahl's earlier work. Our new observations are described in § 2. Section 3 contains a discussion of the star's effective temperature. In § 4 we estimate the interstellar extinction, distance, and luminosity of He 3-519. In § 5 we discuss a set of peculiar UV emission features that are nearly unique to this star. Finally, in § 6, we comment on the size and mass of the large circumstellar shell.

2. OBSERVATIONS

In 1990 July and 1991 May we obtained *IUE* exposures LWP 18426 and LWP 20401, covering the wavelength range 2000–3300 Å at low spectral resolution. LWP 18426 is a double exposure: He 3-519 was placed in two different off-center locations along the major axis of the *IUE* large aperture, with a 60 minute exposure time for each. LWP 20401 is a conventional 80 minute exposure with the star centered in the large aperture. Thus we have data taken at three different locations on the *IUE* detector, with a total exposure time of 200 minutes. A peculiar emission feature around 3008 Å, discussed below, is present in all three spectra; this confirms that the feature is real and that no perceptible change occurred between 1990 and 1991.

In 1991 May we also obtained shorter-wavelength spectra of He 3-519: *IUE* exposures SWP 41663, SWP 41671, SWP 41669, and SWP 41709. These are conventional "low-resolution, short-wavelength, large-aperture" *IUE* data with a total exposure time of 555 minutes; they are useful mainly for estimating the flux level around 1700 Å, since their S/N ratios are too low to show spectral features reliably.

The resulting combined UV spectrum of He 3-519 is shown in Figure 1. This was produced from the two-dimensional *IUE* data in the following way. First, in order to maximize S/N ratios for localized spectral features, one-dimensional spectra were made by "narrow extractions" of the data—that is, we first used data samples only several *IUE* pixels wide perpendicular to the dispersion. Then wider data extractions were also taken, in order to assess the total flux averaged over large wavelength intervals. These were used to renormalize the flux levels in the narrow-extraction spectra. Finally, medians (not averages) were taken of the one-dimensional spectra thus derived from the various independent LWP and SWP exposures. For the LWP wavelength range, where the three expo-

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[5] Beware of potential confusion with a different star, He 3-591 = WRA 751, which has been discussed in recent papers (Hu et al. 1990; van Genderen et al. 1992). The stars He 3-519 and He 3-591 resemble each other enough to make their similar Henize numbers unfortunate.

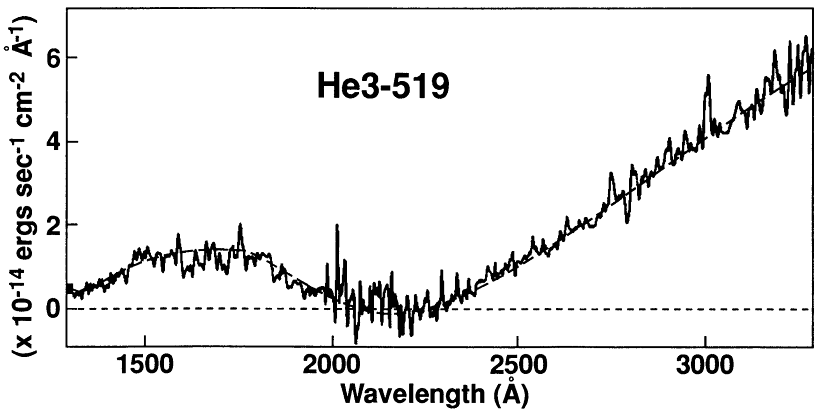

FIG. 1.—UV spectrum of He 3-519, based on *IUE* data as described in the text. At wavelengths shorter than 2700 Å and longer than 3150 Å, the S/N ratio is low and only the continuum level is reliable. Several features between 2700 and 3200 Å are probably real as discussed in the text; the emission feature near 3008 Å is almost certainly real.

sures used different parts of the detector, this median should be almost free of local detector defects as well as cosmic-ray hits.

The S/N ratios are obviously poor in most parts of Figure 1. We think that only about four of the narrow spectral features here are real: two peculiar emission lines near 2753 and especially 3008 Å, a P Cyg profile of Mg II λ2798, and probably He I λ3188 emission. Unfortunately, at wavelengths longer than 3200 Å and shorter than 2600 Å the data are too noisy for detailed analysis—for example, the emission feature at 1750 Å is most likely due to a well-known hot spot in the *IUE* detector, rather than N III] emission. The 2753 and 3008 Å features appear to be real, and we shall discuss them in § 5 below.

The continuum flux levels shown in Figure 1 should be most reliable around 1700 and 2600–3200 Å; our resulting estimate of the interstellar extinction will be outlined in § 4.

We have measured *U*, *B*, *V*, and *R* photometry of He 3-519 and other stars from CCD frames of nine fields covering a 10-arcmin square centered on He 3-519. These were obtained during 1989 February with the 0.9 m telescope on Cerro Tololo, using the TI2 chip in the CCD direct camera. Standard stars from the "E" regions (Graham 1982) were observed each night in order to determine atmospheric extinction and color transformations. All of the CCD data were reduced with DAOPHOT. For He 3-519 we measured $V = 10.92$, $B-V = +1.23$, and $U-B = -0.08$. These values are about 0.05 mag brighter than Stahl's (1986) photometry—a fairly small difference, not much larger than the overall error level.

Classification spectra of He 3-519 and several of the nearby brighter stars selected from the region imaged with the CCD were also observed on 1989 February 1 and 4, using the "2D-Frutti" spectrograph on the 1 m telescope at CTIO. An 831 line mm^{-1} grating was used in second order to give 1–2 Å resolution in the wavelength region 3800–4700 Å. One-dimensional spectra were extracted from the data using IRAF software at Cerro Tololo, and further spectral reductions were done at Minnesota.

Figure 2 shows the blue spectrum of He 3-519. Having prominent emission lines of hydrogen and He I with P Cyg profiles, plus He II λ4686, Si III λ4551, and weak N II λλ4601–4643 emission, this is an Of/WN9 spectrum (cf. Bohannan & Walborn 1989). Figure 2 is consistent with the spectrum of He 3-519 described by Stahl (1986) and also with a spectrogram shown by Walborn (1990); apparently the brightness and spectrum did not change much between 1985 and 1989. The equivalent widths of the hydrogen and He I emission lines are larger than in most other stars of this type. Figure 2 qualitatively resembles the spectrum of AG Car, but that star's emission lines are only half as prominent as those shown here, relative to

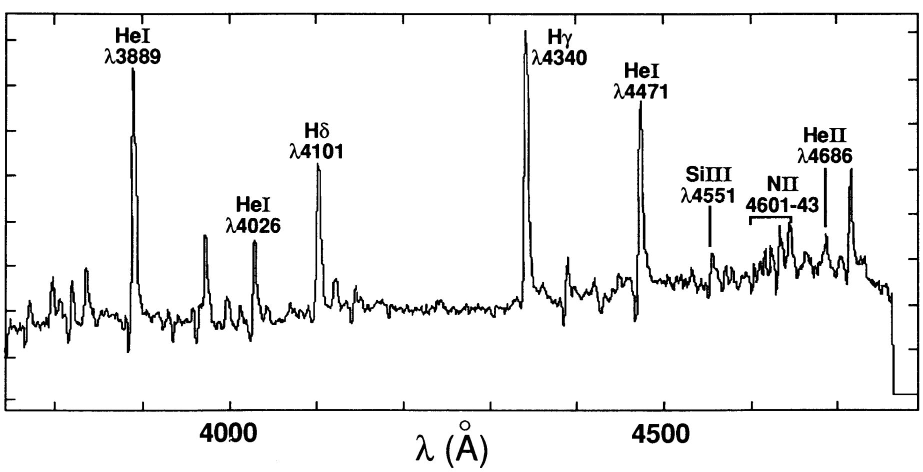

FIG. 2.—Blue spectrum of He 3-519

the continuum. The spectrum of HDE 269582, an Of/WN9 star in the LMC, is quite similar to that of He 3-519 (see Fig. 3 of Bohannan & Walborn 1989).

In § 3 we shall have use for the net equivalent widths of Hγ and He I λ4471 in emission, which are, respectively, about 25 and 10 Å in Figure 2. These values include the star itself but not the large circumstellar shell. Note that the P Cyg absorption component is relatively small for He I λ4471 and even less for Hγ, so these are essentially emission lines, not just P Cyg scattering features.

3. THE EFFECTIVE TEMPERATURE OF He 3-519

Some assumptions about the star's intrinsic continuum are necessary before we can discuss its reddening, distance, and luminosity. He 3-519 is expected to have a high effective temperature, a low surface gravity, and a partially CNO-processed composition. Lacking models for such an atmosphere, here we shall refer to simple blackbody continua with temperatures around 35,000 K. The Planck function approximation, though it may appear naive, should be fairly good in this case. Among the atmosphere models published by Kurucz (1979), those with the lowest gravities at temperatures of 35,000 K or more are close to blackbody curves in the observable wavelength range, and their hydrogen and helium ionization edges at 912 and 504 Å are fairly modest. Moreover, the resemblance to a blackbody tends to improve for lower gravities. In general, everything that we say in this section and the next remains valid if extrapolations of the Kurucz models to lower gravities are used instead of blackbody continua. We prefer the latter for a first analysis, because the Planck function is simple and well defined.

The qualitative appearance of the spectrum shown in Figure 2, with helium and WN-like emission features, indicates a temperature above 30,000 K. The He I λ4471 emission line suggests a somewhat higher temperature, if Zanstra-style reasoning is valid here (and it probably is). The helium emission from the stellar wind or envelope of He 3-519 is quite strong, and the easiest way to excite such strong emission is by recombination following photoionization, as in a nebula. Thus the net He I λ4471 flux indirectly gives a lower limit to the supply of helium-ionizing photons ($\lambda < 504$ Å); in effect the equivalent width of He I λ4471 gives information about the intrinsic stellar continuum flux ratio $F(500\ \text{Å})/F(4471\ \text{Å})$. Omitting further technical details here (the relevant ionic parameters can be found, e.g., in Osterbrock 1989), we note simply that a 35,000 K blackbody continuum provides just enough helium-ionizing photons to explain the strength of He I λ4471 in Figure 2. Although we have not proved that the He I λ4471 excitation is indeed nebula-like, this hypothesis is self-consistent and is the simplest plausible model.

If the Zanstra estimate is valid, the effective temperature may be higher than 35,000 K, for two reasons:

1. The stellar continuum may have a significant helium absorption edge at 504 Å, requiring higher temperatures to achieve the required ionizing photon supply. However, the most nearly applicable Kurucz (1979) models suggest that a temperature adjustment of only a few thousand kelvins would suffice. (Raising the temperature from 35,000 to 40,000 K roughly doubles the equivalent width of He I λ4471 produced by an ionization-limited nebular envelope.)

2. The observed He I λ4471 emission does not count any helium-ionizing photons that escape from the wind or envelope. The large nebular shell centered on He 3-519 is pertinent to this question. According to Stahl (1987), this shell is bright in the [N II] emission characteristic of a low-ionization nebula—which suggests that it is not exposed to a significant flux of helium-ionizing photons (or at least N^+-ionizing photons). This implies that the star's far-UV flux does not greatly exceed the 35,000 K value mentioned above. Further comments on the large circumstellar shell will be made in § 6.

As usual, the He II λ4686 emission is not explained by our simple analysis. But this is probably not a crucial defect, since the observed weak λ4686 emission represents only a tiny fraction of the total helium. If these are recombination lines, then He II λ4686 is produced more efficiently than He I λ4471; so the greater brightness of the latter implies that there must be far more He^+ ions than He^{++}.

In summary, the effective temperature of He 3-519 seems most likely to be in the temperature range 35,000–40,000 K.

4. EXTINCTION, DISTANCE, AND LUMINOSITY

4.1. *The Reddening of He 3-519*

UV observations are critical for obtaining a more reliable estimate of the interstellar reddening. In Figure 3 we have corrected the observed visual-UV continuum of He 3-519 for three sample values of the reddening, $E(B-V) = 1.2$, 1.4, and 1.6, using the standard Savage & Mathis (1979) reddening curve. Here it is convenient to plot the quantity $\lambda^3 F_\lambda$, because this is nearly level for a 35,000 K blackbody in this wavelength range. The most reliable wavelength intervals are indicated by heavier lines in this figure.

The visual wavelength continuum fluxes in Figure 3 are estimated from the B and V magnitudes, corrected for emission lines. We have estimated the emission-line contribution to the B magnitude from the data shown in Figure 2, but for V it was necessary to guess the brightnesses of He I λ5876, Hα, and

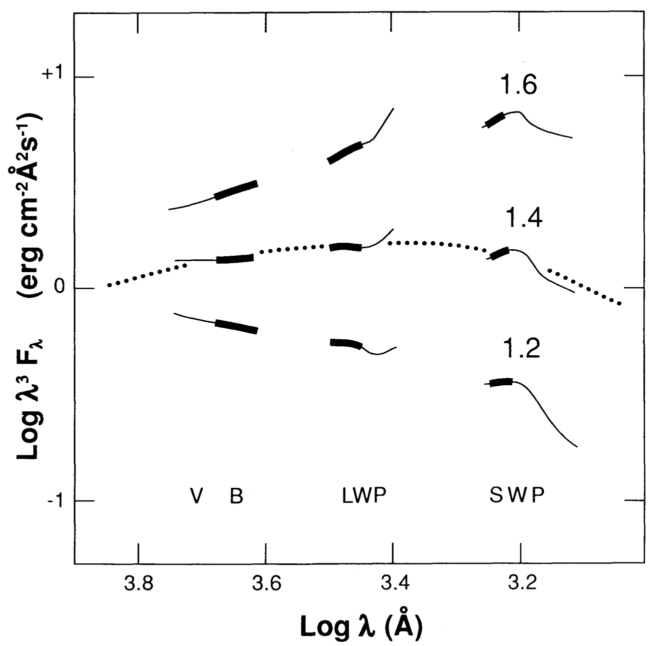

FIG. 3.—Observed continuum of He 3-519, corrected for three different amounts of extinction $A_V = 1.2$, 1.4, and 1.6 mag. Thicker line segments mark intervals where the data are most reliable. Dotted line that passes through the $A_V = 1.4$ values represents a Planck curve with $T = 35{,}000$ K.

other emission lines indirectly, again using the data in Figure 2. Thus, in Figure 3 the continuum flux around 5500 Å is less reliable than that around 4400 Å. The adopted correction for emission lines was 0.10 mag for both B and V.

For estimating apparent continuum fluxes, the *IUE* data are best around 3000 and 1700 Å (see Fig. 1); wavelengths in the interstellar 2200 Å absorption feature are obviously useless in this case.

A 35,000 K Planck function is shown as a dotted curve in Figure 3; it fits the best parts of the observed continuum very well if the reddening is $E(B-V) = 1.4$. A slightly higher reddening, $E(B-V) = 1.5$, similarly fits a 40,000 K blackbody. With $E(B-V) = 1.6$ the continuum resembles a Rayleigh-Jeans spectrum, that is, infinite temperature. Thus the *IUE* data confirm Stahl's (1986) estimate, based on just *UBV* photometry, that $E(B-V)$ is close to 1.5. The visual extinction is about 4.5 mag.

This extinction is mainly interstellar, not circumstellar. If a significant fraction of it were circumstellar, then He 3-519 would be a bright infrared source in the *IRAS* catalog. The source IRAS 10520−6010 probably represents dust around He 3-519, but its total IR luminosity is less than 1% of the star's intrinsic UV luminosity—indicating that the circumstellar extinction is practically negligible. We shall return to the circumstellar dust question in § 6 below.

4.2. *The Reddening vs. Distance Relation*

Figure 4 shows the reddening versus distance relation for several stars in the direction of He 3-519. For these stars we have used the *UBV* magnitudes from four CCD frames (see § 2). We have spectral types from the observing program mentioned in § 2 for those indicated by asterisks, and their adopted distances are based on spectroscopic parallaxes. These stars are listed in Table 1. The stars indicated by plus signs all have $U-B \leq 0.0$, and their distances were estimated from *UBV* photometry alone, assuming that they are main-sequence stars.

Star number 2 in Table 1 is a B2.5 V star only 40″ from the line of sight to He 3-519 and has extinction $A_V = 2.8$ mag at a distance of about 5.9 kpc; this provides a lower limit to the distance of He 3-519 which has $A_V \approx 4.5$. Therefore He 3-519 is at least as distant as AG Car ($D = 6$ kpc, Humphreys, Lamers, & Hoekzema 1989) and is very likely farther—perhaps at about 8 kpc, judging from Figure 4. (AG Car, only half a degree from He 3-519, is also shown in the figure.) In this direction all distances from 2 to 10 kpc fall along the Carina spiral arm. In principle, an improved estimate of the distance of He 3-519 may be obtainable from its radial velocity; but our data do not have adequate spectral resolution for this.

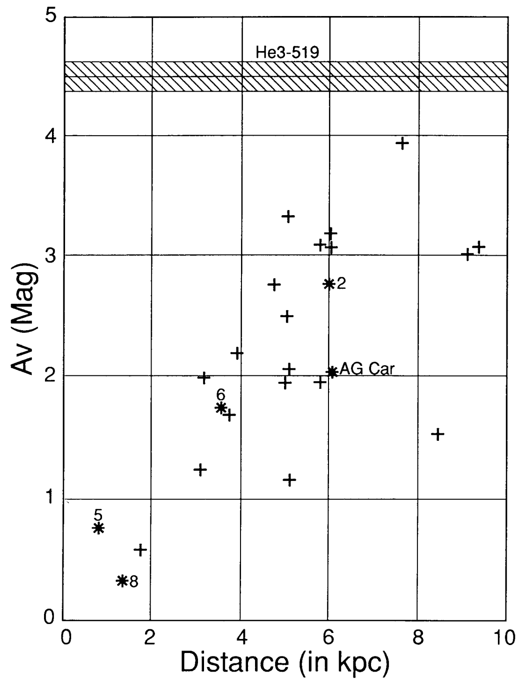

FIG. 4.—Extinction vs. distance for stars close to the line of sight of He 3-519, indicating a probable distance of about 8 kpc for this star. Distances of the numbered stars (*asterisks*) are based on spectroscopy as well as photometry; these are listed in Table 1. Distances of the other stars (*plus signs*) are based on *UBV* photometry assuming that these are main-sequence stars.

4.3. *The Luminosity of He 3-519*

A minimal estimate of the luminosity can be found by fitting the observed fluxes to a 35,000 K blackbody continuum with reddening $E(B-V) = 1.4$, at a distance of 6 kpc: $M_{\text{bol}} = -10.3$. However, He 3-519 is more likely at 8 kpc, and if we assume 40,000 K, $E(B-V) = 1.5$ at this distance, then we obtain $M_{\text{bol}} = -11.7$ mag. The most likely value is between these two examples, and bolometric corrections for the lowest-gravity Kurucz (1979) models lead to essentially the same results. Thus, at the present level of uncertainty it is valid to say that the bolometric magnitude of He 3-519 is roughly −11 mag, and the luminosity is of the order of $2 \times 10^6 L_\odot$, somewhat brighter than AG Car.

5. THE UNIQUE (?) 3008 AND 2753 Å FEATURES

The emission line near 3008 Å in Figure 1 is very unusual; we have not found any other object in the *IUE* archives that

TABLE 1

SUMMARY OF OBSERVATIONS OF STARS WITH KNOWN SPECTRA NEAR He 3-519

Star	R[a]	P.A.[a]	V (mag)	$B-V$ (mag)	$U-B$ (mag)	Spectral Type	A_V (mag)	Distance (kpc)
1..........	23″	188°	11.65	0.83	0.30	G8–K0 V	0.3	0.2
2..........	40	98	14.14	0.65	−0.14	B2.5 V	2.8	5.9
5..........	145	130	11.09	0.22	0.10	A0 V	0.7	0.7
6..........	83	278	11.53	0.33	−0.36	B3–B5 III:	1.6	3.8
7..........	71	269	11.47	0.61	0.18	F5–G0 V:	0.3	0.3
8..........	100	256	11.94	0.12	−0.01	A0–A3 V	0.3	1.3

[a] R and P.A. give the positions relative to He 3-519 accurate to about 2″ and intended for identification puposes only.

shows it at comparable strength. This feature is indeed real, as noted in § 2, and it is potentially important as a hint that He 3-519 is different in some way from other LBV/WN/Of-like stars, or any other stars that we know of. The $\lambda 3008$ emission is spatially unresolved in the *IUE* data on He 3-519, indicating a small, dense region of origin. Since it is broad (FWHM = 17 Å in the *IUE* data), $\lambda 3008$ probably represents a blend of two or more spectral lines. The net equivalent width in emission is about 6 Å.

This feature has one interesting historical precedent: Swings & Struve (1940) detected emission close to the same wavelength in P Cygni and ascribed it to Fe III. This was probably the shortest-wavelength spectral feature discovered in any object outside the solar system by ground-based observations. Struve & Swings's observation is interesting both because P Cyg is a famous LBV and also because $\lambda 3008$ is *not* conspicuous in *IUE* spectra of P Cyg (though it may be present, in some). If their detection was correct, then the near-UV spectrum of P Cyg probably changed between 1940 and 1980.

The identification with Fe III $\lambda\lambda 3002$–3014 is plausible because this is the brightest multiplet in laboratory arc spectra of Fe III (Moore 1952; Kelly 1979). However, it is not obvious why such emission should be prominent in He 3-519 but not in other hot stars with dense envelopes. Relevant energy levels and oscillator strengths are listed by Sugar & Corliss (1985) and Fawcett (1989). Since the energy of the upper level $3d^5(^4G)4p\ ^5F^o$ is rather high (14.4 eV), we suspect radiative excitation in this case. The strongest absorption lines from the ground level have wavelengths around 860 Å and lead to the excited level just mentioned. Decay to $3d^5(^4F)4s\ ^5F$ would then give the $\lambda 3008$ multiplet. If the gas is optically thick in the $\lambda 860$ lines but not in the $\lambda 3008$ lines, then the observed emission might be produced. Enough energy may be available in the stellar continuum if the resonance lines near 860 Å collectively absorb an equivalent width of at least 1 Å (350 km s^{-1}), which seems possible. Alternatively, some other emission line might provide energy for fluorescence, though the only line near 860 Å that we have thought of is due to C II, which seems an unlikely candidate in this higher-ionization context.

The main objection to the radiative-excitation hypothesis is that decays to some other intermediate levels, particularly giving emission around 1890 Å, should have much higher transition probabilities than $\lambda 3008$ (Fawcett 1989). Perhaps the gas is optically thick in these other lines but transparent in $\lambda 3008$; this would allow the latter to be bright after all. These are all metastable levels, which may be collisionally depopulated; $3d^5(^4F)4s\ ^5F$ may possibly be depopulated faster than the others, while the lower oscillator strength for $\lambda 3008$ may be helpful in reducing the optical depth. In any case a detailed analysis to explain the observed emission would be useful; whatever the mechanism, why is it nearly unique to He 3-519? What does this indicate about the stellar wind or envelope of this star?

Our data show another probable emission feature near 2753 Å, with a net equivalent width of the order of 3 Å. The reality of this line is not as certain as that of $\lambda 3008$, and we have not found a likely identification; maybe it is analogous to $\lambda 3008$ but involves some other ion species.

6. THE LARGE CIRCUMSTELLAR SHELL

He 3-519 is surrounded by a gaseous shell almost 1′ across, larger than that of AG Car (Hoffleit 1953; Stahl 1987). The shell radius is about 1.0 pc if we adopt a distance of 8 kpc. If this shell is expanding at 30 to 50 km s^{-1} like other LBV shells (see Walborn 1982; Appenzeller, Wolf, & Stahl 1987; Stahl & Wolf 1986; Hutsemekers & Van Drom 1991), and if the possibility of deceleration is neglected, then its indicated age is of the order of 25,000 yr. (Stahl mentioned a smaller age because he assumed a smaller, and now unlikely, distance for He 3-519.)

Stahl measured the Hα emission-line brightness of the circumstellar shell and used this as an indicator of the ejected mass. His mass estimates now need some revision and clarification, partly because the estimated distance is now greatly increased and partly because assumptions about the electron density are crucial. Suppose that the distance of He 3-519 is $D = 8\eta$ kpc, where η is probably between 0.7 and 1.3 (see § 4). Then Stahl's measurement of Hα (including his correction for extinction) gives an emission-line luminosity $L(\text{H}\alpha) \approx 130\eta^2\ L_\odot$, which is much less than the ionization-limited value; the shell is evidently optically thin to ionizing photons. For the radius and thickness of the shell we adopt $R = 1.0\eta$ pc and $\Delta R = 0.12R$, based on Figure 2 of Stahl (1987).

Suppose, then, that the gas has electron density n_e and fills volume $4\pi\epsilon R^2\,\Delta R$, where of course ϵ is a filling factor less than unity. We also assume that the helium mass fraction is about 0.3 (mostly He°, if the presence of [N II] emission is any indication), and we use an Hα recombination emissivity for a temperature of 10^4 K as quoted by, for example, Osterbrock (1989). Then the electron density needed to explain the Hα luminosity is approximately $n_e \approx 165\eta^{-0.5}\epsilon^{-0.5}$ cm^{-3} and the corresponding mass of the large circumstellar shell is roughly $M_{\text{sh}} \approx 10\eta^{2.5}\epsilon^{0.5}\ M_\odot$. A spectroscopic indication of n_e is needed in order to improve this estimate; meanwhile, for plausible values of η and ϵ the shell mass appears likely to be in the range 1–10 $M_\odot$. The implied material thickness of the shell is too small to cause much circumstellar extinction.

In principle, additional information about the circumstellar mass can be obtained from infrared observations of the imbedded dust. Here we shall present only a simplified discussion of this problem, which is not at all straightforward. He 3-519 and its circumstellar shell appear to coincide with IRAS 10520−6010, which is not as bright an IR source as we might expect from the shell mass estimated above. The rationalized differential luminosity according to the *IRAS* catalog is $\lambda L_\lambda \approx 2000\eta^2\ L_\odot$ at wavelengths 20–70 μm, with a slightly higher upper limit at 100 μm and a short-wavelength cutoff between 25 and 12 μm. The integrated IR luminosity is probably $5000\eta^2\ L_\odot$ or less, which is smaller than the likely stellar luminosity by a factor of the order of 300.

The observed 20–70 μm emission represents a surprisingly small mass of dust, that is, considerably less than 1% of the circumstellar gas mass estimated from the Hα emission. As an example let us consider silicate grains as described by Draine & Lee (1984); at long wavelengths the emission efficiency of such a grain with radius a is approximately proportional to $\lambda^{-2}a$. Let us suppose that most of the dust is in the circumstellar shell shown in Stahl's (1987) image, heated mainly by the stellar UV flux. In that case the equilibrium grain temperature is nearly proportional to $a^{-1/6}$, and the grain-size distribution dN/da required to produce the observed roughly constant λL_λ is proportional to a^{-3}. With this size distribution the total dust mass is proportional to the maximum grain size a_{max}. Assuming a stellar luminosity of $10^{6.4}\eta^2\ L_\odot$, we find: $M_{\text{dust}} \approx (0.004\eta^2\ M_\odot)\ (a_{\text{max}}/\mu\text{m})$; essentially this represents the mass of dust necessary to produce the IR luminosity, and the stellar luminosity is relevant only to the extent that it affects the grain size-temperature relation. The observed (60 μm)/(25 μm) brightness ratio implies that a_{max} is at least 0.3 μm (i.e., some grains must be 65 K or cooler), giving a lower limit to the dust mass, $M_{dust} \gtrsim 0.001\eta^2 M_{\odot}$. If we want M_{dust} to be at least 0.01 $M_{\odot}$, befitting a "normal" several-solar-mass sample of gas, then a_{max} must be several μm. Then the largest grains would be cooler than 50 K and would radiate at low efficiencies, mainly around 100 μm. Since grains this large seem implausible, we conclude that the dust/gas mass ratio is most likely far less than the normal interstellar value 0.01. This conclusion is unchanged if nonsilicate grain materials are assumed.

7. DISCUSSION

He 3-519 is an unusual star even among the already peculiar LBVs. Its most remarkable characteristic is its strong emission-line spectrum, including Fe III (?) λ3008 which may be unique. It is clearly an Of/WN9 star. Strictly speaking He 3-519 is not presently known to be a true LBV, because no outburst or eruption has been observed; an apparent magnitude of roughly 10.5 recorded in 1949–1951 (Henize 1952) appears consistent with photometry done during the 1980s.

However, the massive circumstellar shell discussed in § 6 shows that at least one major mass ejection event occurred in the past. Since He 3-519 is too luminous to have been a red supergiant, presumably that instability represented the LBV stage of evolution. Obviously we must ask whether the star is still an LBV. The "expansion age" of the shell, subject to the usual simplifying assumptions, is of the order of 25,000 yr—about the same as the likely duration of the LBV phase of evolution (see Humphreys 1991). Moreover, the effective temperature estimated in § 3 is rather high for a quiescent LBV. Although large temperature excursions can occur in LBVs (Bohannan & Walborn 1989), the combination here of high temperature with a probably "old" shell leads us to speculate that He 3-519 is near or perhaps even past the end of its LBV phase, and well on its way to becoming a true Wolf-Rayet star.

But some other questions also need to be answered about He 3-519. A detailed theory of the 3008 Å emission mechanism is needed, and a plausible identification of the suspected 2753 Å emission. An accurate radial velocity from a high-resolution spectrum would allow us to set tighter limits on its distance, and a spectrum of the circumstellar shell would let us measure the actual expansion velocity to derive its age, abundances in the ejecta, and the electron density which is necessary to measure the mass of the shell. Another outstanding question is the apparent scarcity of dust in the shell. Far-IR measurements may help confirm or resolve this discrepancy.

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