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He II EMISSION IN EXTRAGALACTIC H II REGIONS[1]

DONALD R. GARNETT
Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

ROBERT C. KENNICUTT, JR.[2]
Steward Observatory, University of Arizona, Tucson, AZ 85721

YOU-HUA CHU[2]
Astronomy Department, University of Illinois, 1002 West Green Street, Urbana, IL 61801

AND

EVAN D. SKILLMAN
Astronomy Department, University of Minnesota, 116 Church Street, S. E., Minneapolis, MN 55455
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ABSTRACT

We present spectroscopic observations which confirm the presence of nebular He II λ4686 emission in the SMC H II region N76 and demonstrate that the He II emission associated with the WO star in IC 1613 is also extended .Several H II regions are now known to show such emission. We discuss the properties of four: N44C and N159F in the LMC, N76, and IC 1613 No. 3. In each case, the He II zone is centered closely on a specific star; in one, an O star, in two, Wolf-Rayet stars, and in N159F the He II is associated with the X-ray binary LMC X-1. N44C has diffuse X-ray emission and high-velocity gas, which suggests the presence of shocked gas. The close correlation of the emission with specific stars argues that photoionization by the stars themselves is the excitation mechanism, and there is some evidence that this may be true for those nebulae ionized by WO stars and perhaps some rare high-excitation WN stars. If this is the case, the derived ratios of He^{+}-ionizing photons to H-ionizing photons yield effective temperatures greater than 60,000 K. However, possible association with diffuse X-ray emission and shocked gas confuses the picture, since some shock models also predict strong He II emission. A third possibility, suggested by Pakull & Angebault for N159F, is that the He II emission results from photoionization by X-rays from massive X-ray binaries. The existence of these nebulae with He II emission increases the likelihood that the λ4686 emission frequently observed in dwarf emission-line galaxies is nebular in origin. This suggests that the radiation field associated with star-forming regions can be harder than previously suspected, and reopens the question of whether photoionization by stars in young galaxies can account for the ionization observed in QSO absorption-line systems. It also raises questions regarding the usefulness of emission-line diagnostics in giant H II regions for exploring the properties of the massive star IMF.

Subject headings: galaxies: Magellanic Clouds — nebulae: H II regions — radiation mechanisms

1. INTRODUCTION

Observations of emission-line ratios have often been used to estimate effective temperatures for the ionizing stars in photoionized nebulae, since it can be difficult to determine effective temperatures directly for very hot stars. Representative studies (for example, Campbell 1988 or Vilchez & Pagel 1988) have suggested that the hottest ionizing stars in giant H II regions (where one might expect to find the hottest main-sequence stars) typically have T_{eff} less than 60,000 K. Higher temperatures are generally ruled out because of the absence of emission lines from high-ionization species such as He^{++}. However, since 1985 several H II regions in Local Group galaxies have been found to exhibit He II emission which is demonstrably nebular in origin. In this paper, we will present new observations for two of these nebulae, discuss the properties of the nebulae as a group, and examine some of the possible origins for the He II emission.

2. OBSERVATIONS

The H II region No. 3 in IC 1613 (Sandage 1971) was observed using the Red Channel CCD Spectrograph on the 4.5 m Multiple Mirror Telescope (MMT). The wavelength coverage was 3660–4940 Å at ≈7 Å resolution. The 2″ by 180″ slit was positioned to include the Wolf-Rayet star discovered by Davidson & Kinman (1982) and D'Odorico & Rosa (1982). N76 in the SMC (Henize 1956) was observed with the 2D FRUTTI on the 1.5 m reflector at Cerro Tololo Inter-American Observatory. The spectrum covered 3600–6950 Å at ≈8 Å resolution. The 7″.8 by 300″ slit was centered on the Wolf-Rayet binary AB 7 (Azzopardi & Breysacher 1979). Unfortunately, for this observation severe *S*-distortion in the 2D-FRUTTI caused part of the red end of the spectrum to run off the edge of the detector. The result is that, for the region redward of 6000 Å, some 30 columns of the image fall onto a noisy/dead section of the detector. We therefore cannot use integrated emission-line strengths from that part of the N76 spectrum. Our spectra of N76 and IC 1613 No. 3 are displayed

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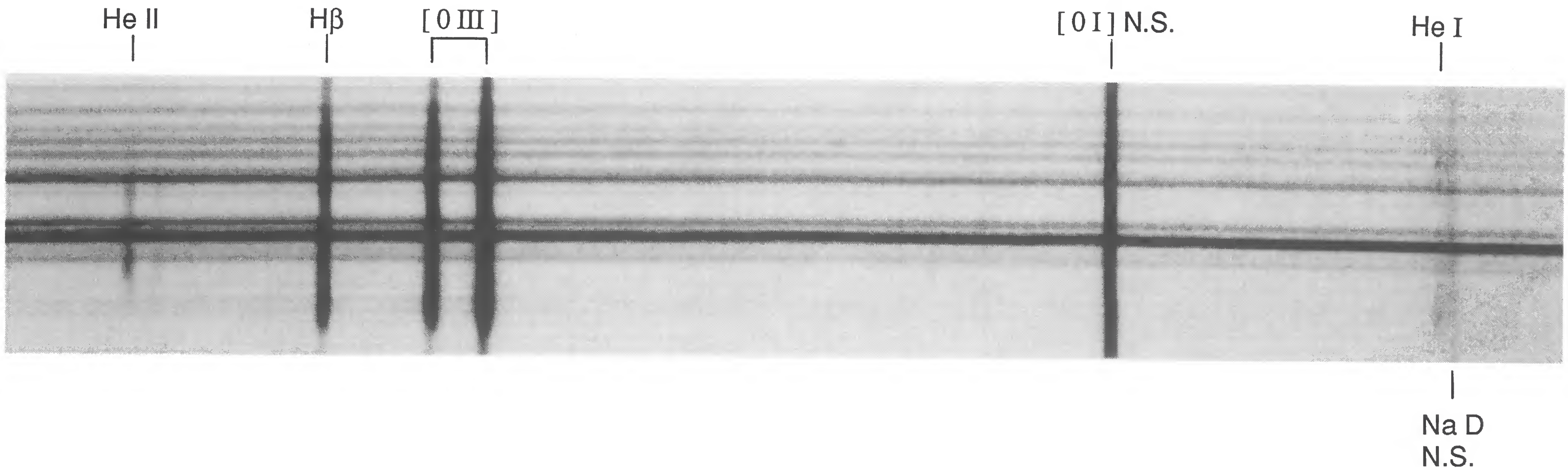

FIG. 1*a*

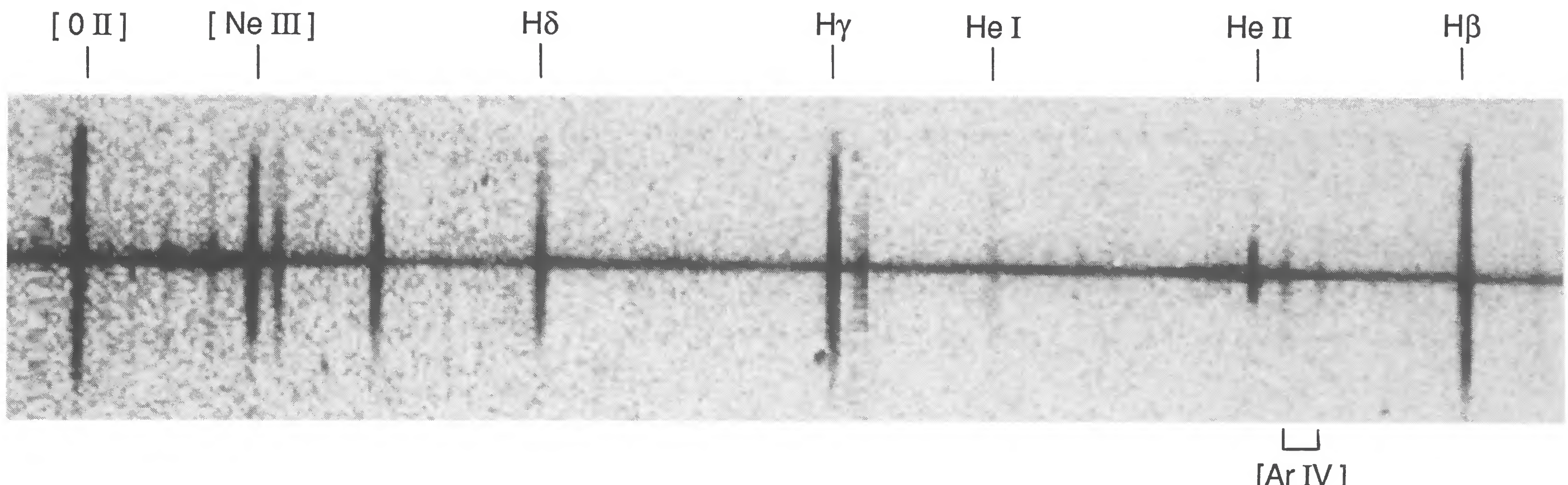

FIG. 1*b*

FIG. 1.—(*a*) Portion of CTIO 2D-FRUTTI spectrum of H II region N76 in the SMC, showing the spatially extended nature of the He II λ4686 emission. Compare the appearance of the He I λ5876 line at the far right. The width of the image (vertical dimension) corresponds to 300″ on the sky. (*b*) MMT CCD spectrum of IC 1613 No. 3, again demonstrating the nebular character of the λ4686 emission. The vertical dimension in this image corresponds to 180″ on the sky.

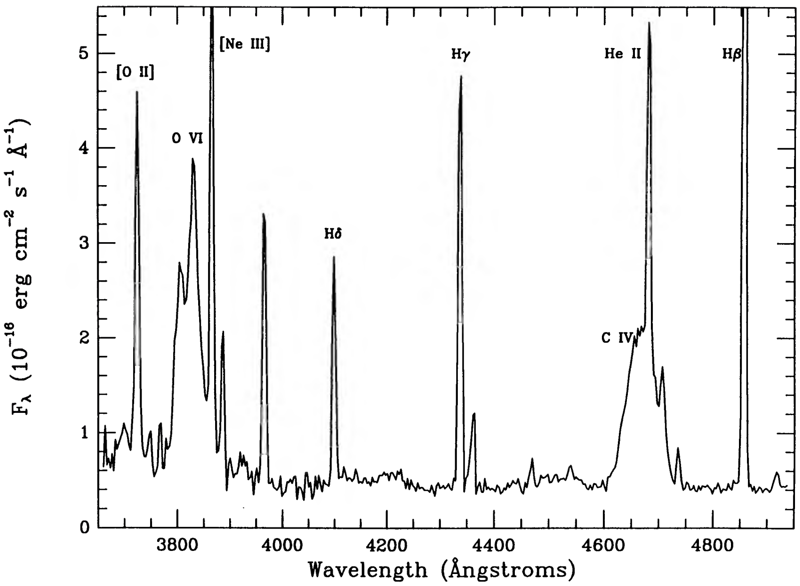

FIG. 2.—The integrated spectrum of IC 1613 No. 3, showing the broad stellar emission features due to O VI near 3830 Å and C IV near 4670 Å, as well as the strong, narrow He II 4686 Å line.

in Figures 1 and 2. These spectra confirm the presence of nebular He II emission in N76 noted by Testor & Pakull (1989), and show directly that the He II emission in IC 1613 No. 3 is spatially extended (see, e.g., Davidson & Kinman 1982, who had only one-dimensional spectra).

The amount of interstellar reddening was estimated from the Balmer decrement for an electron temperature of 15,000 K and density 100 cm^{-3}. For IC 1613 No. 3, we obtain a small logarithmic extinction coefficient $C(\mathrm{H}\beta) = 0.05 \pm 0.15$, which compares well with the value $C(\mathrm{H}\beta) = 0.11$ obtained by Davidson & Kinman (1982). For N76, we derive $C(\mathrm{H}\beta) \approx 0.2$ from Hα/Hβ, which is somewhat high compared to the values 0.04–0.18 derived by Dufour & Harlow (1977). Assuming $C(\mathrm{H}\beta) = 0.2$ for N76, our corrected Hβ surface brightness is 25% higher than Dufour & Harlow's average value of 1.7×10^{-15} ergs cm^{-2} s^{-1} arcsec^{-2}. If we compare the *total* Hβ flux of 9.4×10^{-11} ergs cm^{-2} s^{-1}, derived from our uncorrected Hβ surface brightness assuming a nebular diameter of 300″, with the total Hα flux of 2.8×10^{-10} ergs cm^{-2} s^{-1} measured by Kennicutt (1988), we obtain a reddening coefficient $C(\mathrm{H}\beta) \approx 0.1$. Fortunately, $F(\lambda4686)/F(\mathrm{H}\beta)$ is very insensitive to uncertainties in reddening: two magnitudes of interstellar extinction are required to change $F(\lambda4686)/F(\mathrm{H}\beta)$ by 10%. We therefore estimate that for N76 and IC 1613 No. 3 $F(\lambda4686)/F(\mathrm{H}\beta)$ is accurate to within 20%, but that emission-line luminosities could be much more uncertain. Table 1 lists the observed corrected Hβ flux and the $I(\lambda4686)/I(\mathrm{H}\beta)$ ratio measured within the observing aperture, the angular radii of the H$^+$ and He^{++} emitting zones in arcseconds, and the mean emission-line surface brightnesses for Hβ and λ4686 in N76 and IC 1613 No. 3 measured within the corresponding emitting zones. The H$^+$ and He^{++} diameters for N76 and IC 1613

TABLE 1

PROPERTIES OF H II REGIONS WITH He II EMISSION

Quantity	IC 1613 Number 3	SMC N76	LMC N44C[a]	LMC N159F[b]
$F(\mathrm{H}\beta)$[c] (ergs cm^{-2} s^{-1})	$(2.5 \pm 0.6) \times 10^{-14}$	$(4.9 \pm 1.6) \times 10^{-12}$	5.2×10^{-12}	...
$\dfrac{I(\lambda4686)}{I(\mathrm{H}\beta)}$	0.16 ± 0.01	0.13 ± 0.02	0.08	...
Slit size	2″ × 180″	6″ × 300″	4″ × 4″	...
$R(\mathrm{H}^+)$	20″	150″	15″	...
$R(\mathrm{He}^{+2})$	6″	60″	6″	...
$S(\mathrm{H}\beta)$ (ergs cm^{-2} s^{-1} arcsec^{-2})	3.1×10^{-16}	2.1×10^{-15}	1.6×10^{-13}	...
$S(\lambda4686)$ (ergs cm^{-2} s^{-1} arcsec^{-2})	1.7×10^{-16}	6.8×10^{-16}	1.4×10^{-14}	...
T_e (K)	16,000[d]	15,000[e]	12,000	13,500
$L(\mathrm{H}\beta)$ (ergs s^{-1})	2.8×10^{37}	1.1×10^{38}	4.4×10^{37}	3.2×10^{36}
$L(\lambda4686)$ (ergs s^{-1})	1.4×10^{36}	5.7×10^{36}	6.3×10^{35}	1.5×10^{35}
$Q(\mathrm{H}^0)$ (photons s^{-1})	6.6×10^{49}	2.5×10^{50}	9.6×10^{49}	7.0×10^{48}
$\dfrac{Q(\mathrm{He}^+)}{Q(\mathrm{H}^0)}$	0.026	0.027	0.0070	0.024

[a] Data from Stasińska, Testor, & Heydari-Malayari 1986.
[b] Pakull & Angebault 1986.
[c] Measured within spectrograph slit, corrected for reddening.
[d] Davidson & Kinman 1982.
[e] Dufour & Harlow 1977.

No. 3 were taken to be the FWHM of the spatial profile of the Hβ and λ4686 lines, respectively.

3. NEBULAR AND STELLAR PROPERTIES

There are now several H II regions known to have strong nebular He II emission. We will discuss the four best-observed extragalactic cases here: N44C and N159F in the LMC, N76, and IC 1613 No. 3. (Pakull 1991 and Niemela, Heathcote, & Weller 1991 present evidence for several new nebulae with He II emission.) The case of N159F/LMC X-1 was discussed in detail by Pakull & Angebault (1986), while Stasińska, Testor, & Heydari-Malayeri (1986) and Pakull & Motch (1989) have presented analyses of N44C. Table 1 lists derived properties of these four nebulae: the electron temperature T_e; the Hβ and λ4686 emission-line luminosities; and the H- and He$^+$-ionizing photon luminosities $Q(\mathrm{H}^0)$ and $Q(\mathrm{He}^+)$, respectively, derived assuming the emission arises from photoionization and recombination. The total flux in each emission line was derived by taking the observed mean surface brightness and multiplying it by the total angular area of the emitting region for each line, assuming spherical geometry. These fluxes were then used to derive the emission-line luminosities, assuming distances of 57, 78, and 770 kpc to the LMC, SMC, and IC 1613, respectively. $Q(\mathrm{H}^0)$ and $Q(\mathrm{He}^+)$ were derived from the emission-line luminosities using the relations

$$Q(\mathrm{H}^0) = \frac{L(\mathrm{H}\beta)}{j(\mathrm{H}\beta)/\alpha_B(\mathrm{H}^0)}$$

$$Q(\mathrm{He}^+) = \frac{L(\lambda 4686)}{j(\lambda 4686)/\alpha_B(\mathrm{He}^+)}\ ;$$

$j(\mathrm{H}\beta)$, $j(\lambda 4686)$, $\alpha_B(\mathrm{H}^0)$, and $\alpha_B(\mathrm{He}^+)$ were taken from Tables 4.2, 4.3, 2.1, and 2.8 of Osterbrock (1989). The ratio $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ derived in this way has only a $T^{-0.15}$ dependence on the electron temperature, is largely insensitive to interstellar reddening, and is independent of the abundance of helium in the nebula. The uncertainties in $Q(\mathrm{He}^+)$ and $Q(\mathrm{H}^0)$ individually can be relatively large, as they depend essentially upon the accuracy of the absolute spectrophotometry and our assumptions regarding nebular geometry, but the ratio of the two quantities should be more reliable. The uncertainty in the derived values of $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ is determined mainly by the uncertainty in the relative λ4686/Hβ line ratio. However, the $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ values listed in Table 1 do not necessarily represent the values intrinsic to the hottest ionizing star in each object; other, cooler stars may contribute to the ionization, particularly in the case of N76. Based upon non-LTE H-He stellar atmosphere calculations by Husfeld et al. (1984) and Clegg & Middlemass (1987), the derived values of $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ correspond to T_{eff} in the narrow range 70,000–80,000 K (see Fig. 3); here we have assumed that those stellar atmosphere models closest to the Eddington limit (that is, those with the lowest gravities; these are only 0.2 in log g below the Eddington limit) are the most appropriate for our comparison. Obviously, the plane-parallel, hydrostatic atmospheres discussed here are unlikely to be appropriate models for Wolf-Rayet atmospheres. Therefore, we merely treat these values for T_{eff} as being indicative of the hardness of the radiation field. In fact, more recent atmosphere calculations for OB stars (the "unified" models of Kudritzki et al. 1991) which incorporate spherical radiation transfer and the effects of an extended stellar wind predict a much larger luminosity for photons with energies greater than 54 eV. In these models the He II ionizing continuum does not arise from the photosphere, but rather from the extended wind. In Figure 3 we show (by the open squares and dashed curves) results from the new models presented by Kudritzki et al. (1991) for main-sequence and supergiant O stars. The "unified" models give roughly a 2.5 dex increase in the number of He$^+$ ionizing photons for stars in the range 35,000 K < T_{eff} < 52,000 K. This still falls roughly an

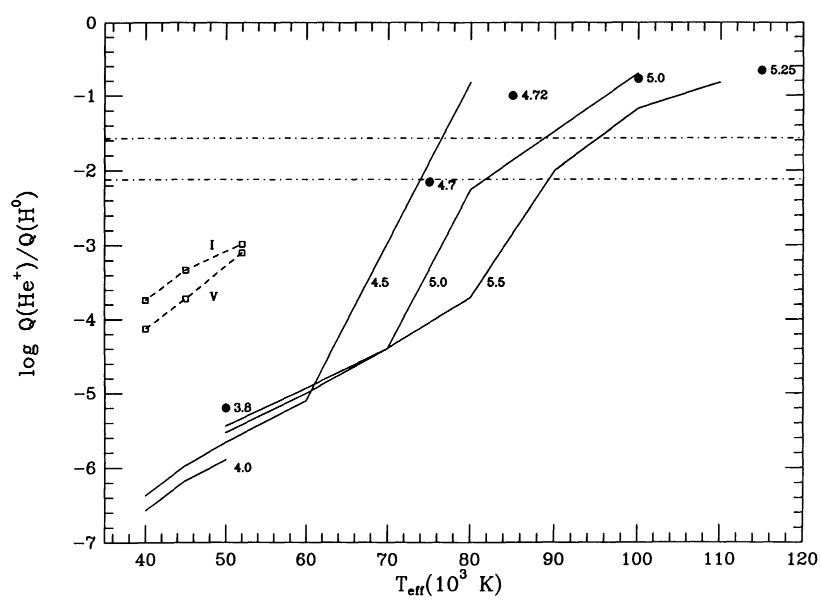

FIG. 3.—The ratio of the number of He$^+$-ionizing photons to the number of H^0-ionizing photons, derived from non-LTE stellar atmosphere computations, plotted as a function of stellar effective temperature. The solid curves connect models with constant log g from Clegg & Middlemass (1987), while the filled circles represent models from Husfeld et al. (1984). The dashed curves represent the more recent "unified" models of Kudritzki et al. (1990) for main-sequence and supergiant O stars. Each curve and point is labeled with the value of log g of the stellar model. The range of $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ observed in the nebulae with He II emission lies between the dot-dashed lines.

order of magnitude short of the numbers required to explain the nebulae discussed here. Extrapolation of the unified models to higher $T_{\rm eff}$ suggests that one can explain the observed nebular He II emission with stars having $T_{\rm eff} > 60{,}000$ K, still significantly above the highest observed temperatures for O stars. Note that a factor of 2 uncertainty in $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ increases the range of possible $T_{\rm eff}$ by only ± 5000 K; $Q(\mathrm{He}^+)/Q(\mathrm{H}^0)$ is very sensitive to $T_{\rm eff}$ in this temperature range. Our values for $T_{\rm eff}$ are smaller than that derived by Davidson & Kinman (1982) for the ionization source in IC 1613 No. 3; their 6″ aperture did not span the full extent of the nebula, thereby excluding most of the H^+ emission.

In each of the four nebulae, the He II emission is centered on a specific star. In N159F, the star is the massive X-ray binary LMC X-1 (Pakull & Angebault 1986); in N44C, it appears to be an O4-O6 star (Pakull & Motch 1989); and in SMC N76 it is the spectroscopic binary AB 7, which Pakull & Bianchi (1991) now classify as WN1 + O6 IIIf based upon recent observations. For IC 1613 No. 3 the exciting star appears to be a WO star (Davidson & Kinman 1982); from the D'Odorico & Rosa (1982) and Davidson & Kinman spectra, O V λ5590, if present, is weak compared to C IV $\lambda\lambda$5801, 12, while the O VI $\lambda\lambda$3811, 3834 feature is comparable in strength to C IV λ4658 (see Fig. 2). On this basis, we tentatively classify the star as WO4.

Besides the association of N159F with LMC X-1, diffuse X-ray emission has been observed in the N44 complex, some of which is seen in the region containing N44C (Chu & Mac Low 1990). Also, Goudis & Meaburn (1984) discovered ionized gas in N44C having a velocity of 120 km s^{-1} with respect to the H II region. This high-velocity gas appears to be close to the position of the suspected ionizing star (star 2 in Stasińska, Testor, & Heydari-Malayeri 1986).

4. IONIZATION MECHANISMS

What is the source of the He II emission in these nebulae? The data accumulated thus far do not lead to a completely clear picture yet. We can identify three possible mechanisms for producing He II emission:

1. *Hot stellar ionizing continua.*—The association of the He II emission with specific stars in each nebula argues in favor of the stars as the source of ionization for He II. However, classical nebulae ionized by O stars having $T_{\rm eff} < 55{,}000$ K are not expected to produce such strong He^{++}; the plane-parallel non–LTE atmosphere models for such stars discussed in the previous section fall short of producing the required number of He^+ ionizing photons by roughly four orders of magnitude (Fig. 3), and even the "unified" atmosphere models fall significantly short. On the other hand, models for massive star evolution which include mass loss (Maeder & Meynet 1987) predict that the most massive stars evolve blueward to effective temperatures greater than 75,000 K on their way to becoming Wolf-Rayet stars; Stasińska, Testor, & Heydari-Malayeri (1986) suggested that this could explain the apparent high effective temperature for star 2 in N44C. Recent determinations of $T_{\rm eff}$ for Population I Wolf-Rayet stars suggest that some may have such high effective temperatures at their photospheres (Pauldrach et al. 1985; Schmutz, Hammann, & Wessolowski 1989), but H II regions containing WN or WC stars generally do not exhibit He II emission. On the other hand, Pakull (1991) hypothesizes that very early WN-type stars do have $T_{\rm eff}$ high enough to excite He II emission, a hypothesis which appears to be supported by $T_{\rm eff}$ measurements for Wolf-Rayet stars (Schmutz et al. 1989).

Dopita et al. (1990) found very strong nebular He II emission in the nebula G2.4 + 1.4, which contains the WO1 star WR 102 = Sand 4. The spectrum of G2.4 + 1.4 observed by Dopita et al. argues strongly in favor of photoionization as the mechanism by which the nebula is excited; none of the characteristic features of shock excitation are observed, and the $\lambda 4686/\mathrm{H}\beta$ intensity ratio is much larger than predicted by any shock model. The presence of strong He II emission in this object and in IC 1613 No. 3 argues that WO stars have very hot ionizing continua. Inspection of narrow-band images of the LMC and SMC (Lasker 1979; Davies, Elliott, & Meaburn 1976) show that the WO stars in the Magellanic Clouds are both associated with ring-shaped nebulae. The regions of these nebulae nearest the WO star involved have strong [O III] emission, with [O III]/Hα higher than in more typical Magellanic Cloud H II regions, suggesting high stellar effective temperatures. A search for He II emission in these objects would test the hypothesis that WO stars have very high temperatures.

2. *Shock excitation.*—Models for radiative shocks (Binette, Dopita, & Tuohy 1985; Shull & McKee 1979) indicate that shocks can produce relatively strong He II emission under certain conditions. The strength of the He II emission appears sensitive mostly to the velocity of the shock, rising very sharply to a maximum for $V_{\rm shock} \approx 120$ km s^{-1}, dropping rapidly at higher velocities, and then rising slowly again at very high shock velocities as shown in Figure 4. Chu & Mac Low (1990) have found diffuse X-ray emission in several OB/H II associations in the LMC, including a local peak in N44C, which they interpret in terms of emission from an off-center SNR within a wind-blown superbubble. Moreover, Goudis & Meaburn (1984) discovered a weak component of Hα in N44C at a radial velocity of about -120 km s^{-1} with respect to the nebula. On the other hand, none of the four H II regions with He II emission show any other signatures of shock excitation, such as unusually strong emission from [S II] and [O I], as have been observed in giant H II regions with embedded SNRs (Skillman 1985; Chu & Kennicutt 1986). In addition, the electron temperatures in these nebulae are not unusually high, as are seen in classical SNRs (see, for example, Blair, Kirshner, & Chevalier 1981); the observed electron temperatures are quite comparable to those observed in H II regions having comparable oxygen abundances. Radio continuum measurements of these nebulae could be used to test for the presence of shocks, as well as searches for high-velocity gas and diffuse X-ray emission.

3. *Photoionization by X-rays.*—Pakull & Angebault (1986) demonstrated that the X-ray emission from LMC X-1, extrapolated into the extreme UV assuming a thermal spectrum, was sufficient to produce the observed He^{++} in the surrounding nebula N159F. None of the other He II emitting nebulae have known X-ray point sources, although N44C, as noted, does appear in the X-ray survey of Chu & Mac Low (1990). Pakull & Motch (1989) have interpreted the He II emission in N44C in terms of a fossil X-ray ionized nebula powered by an X-ray source which has switched off within the past century. This seems inconsistent with their classification of star 2 as a main-sequence star, but the luminosity class may still be quite uncertain. We have looked closely for an X-ray source within N76, but the area is confused by X-ray emission from the bright nearby oxygen-rich SNR 0102−72.3. No WO star has been identified with an X-ray source.

5. CONNECTION TO STARBURSTS

The existence of nebular He II emission in H II regions may be relevant to the study of starbursts. Kunth & Sargent (1983)

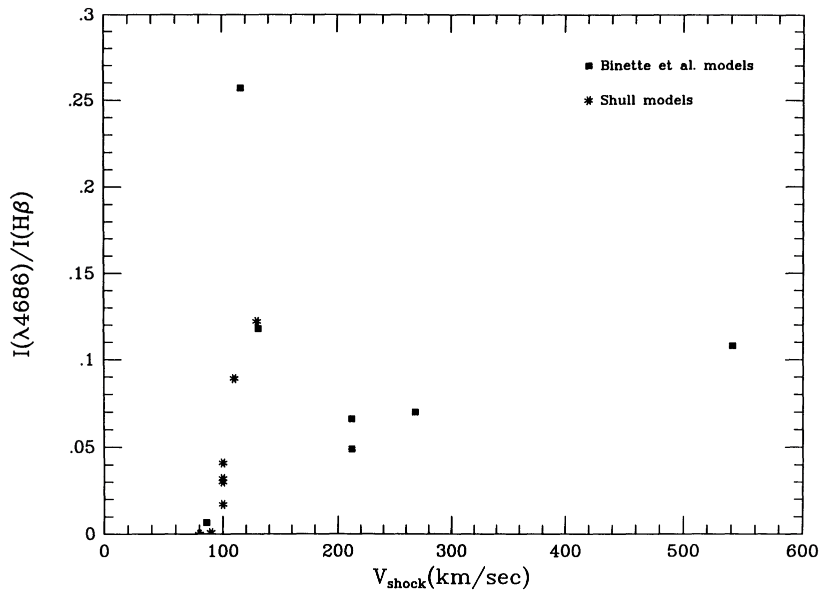

FIG. 4.—The intensity of He II $\lambda4686$ emission relative to Hβ plotted as a function of shock velocity, as determined from models for radiative shocks. Filled squares refer to the models of Binette et al. (1985), while the asterisks correspond to models from Shull & McKee (1979).

and Campbell, Terlevich, & Melnick (1986; hereafter CTM) studied giant H II complexes in dwarf emission-line galaxies. Out of 44 objects observed by these two groups, 17 had apparently narrow He II emission, with an average $\lambda4686$/Hβ ratio of ~ 0.02. The He II emission in the dwarf emission-line galaxies could arise in the atmospheres of Of stars (Bergeron 1977). However, the emission could be nebular, as suggested by the He II emitting nebulae discussed in the previous sections; observations made to date have had neither the spatial nor the spectral resolution to distinguish between the two cases.

An example is shown in Figure 5, where we present data from a CCD spectrum of I Zw 18, taken with the 2.7 m reflector at McDonald Observatory. The figure shows the spatial variation of the emission from Hβ, $\lambda4686$, and continuum along the slit. The $\lambda4686$ emission appears to be more extended than the continuum emission in the NW H II region (He II emission is absent in the SE region). The significance of this result is not very high because of the large uncertainties in the observed $\lambda4686$ fluxes and the relatively low spatial resolution, but it is suggestive, and we hope that this will inspire improved future observations. We measure $I(\lambda4686)/I(\mathrm{H}\beta) = 0.032 \pm 0.002$ in I Zw 18, which yields $Q(\mathrm{He}^+)/Q(\mathrm{H}^0) = 0.010 \pm 0.001$ for the observed electron temperature of 20,000 K. This corresponds to an effective temperature

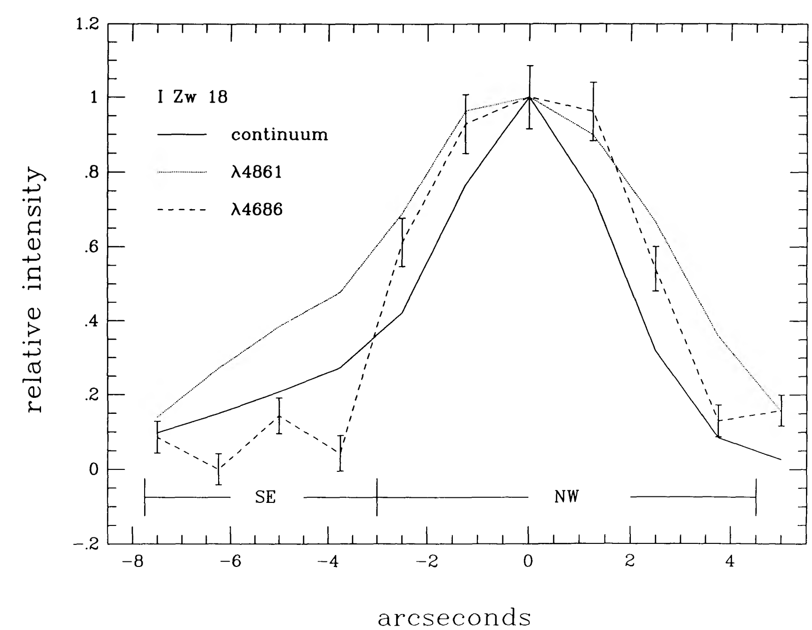

FIG. 5.—The spatial distribution of emission from Hβ, He II $\lambda4686$, and continuum from a McDonald Observatory longslit CCD spectrum of I Zw 18. The solid line shows the distribution of continuum emission, while the dashed line shows the distribution of $\lambda4686$ emission and the dotted line the Hβ emission. All three curves are normalized to the same value where the continuum emission is strongest. The error bars represent 1 σ observational uncertainties for the $\lambda4686$ intensities.

between 70,000 and 80,000 K for the ionization source in I Zw 18, based upon the hydrostatic, plane-parallel model atmospheres. This estimate for T_{eff} is consistent with that derived by comparing measurements of O^+/O^{+2} and S^+/S^{+2} in I Zw 18 with photoionization model predictions (see Fig. 6 of Garnett 1989).

The λ4686 luminosities for the dwarf emission-line galaxies displaying He II emission in the CTM sample range from 6.6×10^{36} ergs s^{-1} for Mrk 36 to 3.3×10^{40} ergs s^{-1} for the much more luminous object C 08-28A. Scaling directly from the observed He II luminosity of the nebula surrounding LMC X-1, these λ4686 luminosities imply the presence of anywhere from 40 to 2.2×10^5 massive X-ray binary systems within the star-forming regions, assuming LMC X-1 is typical. This can be compared with estimates of the number of X-ray binaries made from the few existing X-ray observations of dwarf star-forming galaxies (Fabian 1985). The X-ray luminosities for such galaxies are of order 10^{40}–10^{41} ergs s^{-1}, corresponding to 100–1000 massive X-ray binaries similar to LMC X-1. Alternatively, the number of WO stars like the one in IC 1613 needed to explain the He II emission is ∼10 times smaller than the required number of X-ray binaries. However, few dwarf starbursts are known to contain Wolf-Rayet stars, and none have been reported to contain WO stars. Of course, one could envision a mix of stellar types contributing to the observed He II emission, including Of stars.

One might expect starbursts to generate large numbers of X-ray binaries and Wolf-Rayet stars. If the He II emission in the H II regions described here is due to photoionization, either by hot stars or by X-ray binaries, the implication is that the radiation field within a giant star-forming region can be much more energetic than previously suspected. It has been claimed (e.g., Steidel & Sargent 1989) that the far-UV flux from young galaxies producing early-type stars is not sufficiently energetic to account for the ionization of QSO absorption-line systems. However, it is clear from the phenomenon discussed here that the contribution of young galaxies may need to be reexamined.

The nebular He II phenomenon may have even greater impact on studies of the IMF. Several independent studies using a variety of emission-line ratios have produced convincing evidence that the maximum value of T_{eff} for the ionizing stars in giant H II regions varies as a function of the metal abundance (Stasińska 1980; Campbell 1988; Vílchez & Pagel 1989). This variation has been taken as evidence that the upper mass limit for star formation is a function of metallicity (e.g., Shields & Tinsley 1976), although such a variation should be at least partly due to the fact that the position of the zero-age main sequence varies with metallicity (Leitherer & Langer 1990). However, the possible presence of large numbers of very hot evolved stars or luminous X-ray binaries in giant H II regions will confuse the issue. Therefore, it is quite possible that emission-line diagnostics for giant H II regions will be found to be unreliable tools for inferring properties of the IMF for massive stars.

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