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TWO NEW WOLF-RAYET STARS AND A LUMINOUS BLUE VARIABLE STAR IN THE QUINTUPLET (AFGL 2004) NEAR THE GALACTIC CENTER

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ABSTRACT

As part of an 1800 pc^2 survey of the Galactic center region in the lines of He I (2.058 μm), Brγ (2.166 μm), and the He II/C IV complex (3.09 μm), we have found two new Wolf-Rayet stars, a WN9 and a WC9, near the Galactic center. *K*-band spectra of both stars show broad helium emission lines, and the WC9 shows broad carbon emission lines. A third emission-line star in the region has a spectrum and luminosity similar to a luminous blue variable (LBV). The stars are within 2 pc, in projection, of the Quintuplet cluster (AFGL 2004) and are probably members of this cluster on the basis of their proximity and expected ages.

All three stars are evolved descendants of massive main-sequence stars having $M_{\rm initial} \gtrsim 50\,M_\odot$ (WC9), $\gtrsim 20\,M_\odot$ (WN9), and $\gtrsim 40\,M_\odot$ (LBV candidate). The LBV candidate has a luminosity of $L \approx 10^{6.3}\,L_\odot$, comparable to that of η Carinae ($L = 10^{6.5}\,L_\odot$), one of the most luminous stars in the local group of galaxies.

A total of five emission-line stars are now known to reside in the Quintuplet, and they collectively produce $N_{\rm Lyc} \approx 10^{49}$ photons s^{-1}. The new LBV candidate generates enough ionizing photons to account for the "Pistol" H II region (G0.15−0.05), while the nearby "Sickle" (G0.18−0.04) may be ionized by a population of O stars accompanying the five emission-line stars.

Subject headings: galaxies: nuclei — Galaxy : center — stars : early-type — stars : formation — stars : Wolf-Rayet

1. INTRODUCTION

The large interstellar extinction to the Galactic center, $A_V \approx 27$, obscures the types and spatial distribution of stars near the center, a problem circumvented by employing infrared cameras operating at wavelengths at which the extinction is about $\frac{1}{10}$ the value at optical wavelengths. We performed a survey to assess the ubiquity of young, hot, and luminous stars near the Galactic center by observing an area $\sim 24'$ NS $\times$ $12'$ EW ($= 60 \times 30$ pc) in narrow-band filters centered on the emission lines of He I (2.058 μm), C IV (2.078 μm), Brγ (2.166 μm), and C IV/He II (3.092 μm) (Figer 1995). Preliminary data reduction has revealed two new helium emission-line stars in the Quintuplet region (AFGL 2004) (Nagata et al. 1990; Okuda et al. 1990; Glass, Moneti, & Moorwood 1990). We classify these stars as WC9 and WN9. A third star, which Moneti, Glass, & Moorwood (1994) refer to as the "serendipitous" source, shows narrow emission lines similar to lines seen in the spectra of LBVs; our data suggest that it is one of the most luminous stars in the Galaxy, $L/L_\odot = 10^{6.3}$.

2. OBSERVATIONS

We obtained narrow-band images on five nights in 1994 June, and spectra on five nights in 1994 July. The UCLA double-beam near-infrared camera (McLean et al. 1993, 1994) was used on the University of California Observatories' (UCO) 3 m Shane telescope for both runs, giving a plate scale of 0\".70 per pixel for the short-wavelength channel and 0\".68 per pixel for the long-wavelength channel. For the 2 μm narrow-band images, the frames were dark-subtracted, and then sky-subtracted and flat-fielded by using medianed images of a heavily extincted "dark spot" near the Galactic center at R.A. $17^{\rm h}41^{\rm m}37^{\rm s}$, decl. $-28°53'00''$ (1950). These steps were accomplished for the 3 μm images by using mode-scaled running medians of adjacent survey frames. Spectra were obtained using grisms and a fixed slit of dimensions 1\".4 (2 pixels) by 120\". The final spectra were extracted following the procedures in Massey, Valdes, & Barnes (1992) and are discussed in detail by Figer (1995). The FWHM for unresolved lines was ≈ 38 Å (525 km s^{-1}) in the *K* band. A stars were observed at a similar time and air mass to the targets in order to correct for atmospheric absorption. Brackett series absorption was removed from these spectra by interpolation. Wavelength calibration was done using OH sky lines (Ramsay, Mountain, & Geballe 1992).

Star 1 was observed for 18 minutes on July 22 and July 26. The "Quintuplet" star, q1 (nomenclature from Moneti et al. 1994), was used as an intermediate atmospheric standard; both stars were in the slit at the same time. Star 2 was observed for 12 minutes on July 26, and the A2 V star BS 6378 ($T = 9120$ K; Johnson 1966) was used as the atmospheric standard. Star 3 was observed for 6 minutes on July 26, and the atmospheric standard was BS 6378. WR 121 (WC9) was observed for 1 minute on July 26, and the A2 V star BS 7598 was used as the atmospheric standard.

The dereddened and flux-calibrated spectra (Figs. 1–3) were scaled so that the flux density matched the photometry measured in June. Note that the intensity scale of the spectrum for WR 121 has been divided by 10 to allow a better comparison with the spectrum of star 2. Table 1 contains photometry, using a 4\".2 diameter aperture, and presents line widths for the He I line at 2.058 μm. As a check, we find $\Delta V_{\rm FWHM} \approx 810$ km s^{-1} for the AF star; this compares well with values found previously (800 km s^{-1}, Blum, DePoy, & Sellgren 1995a; 920 km s^{-1}, Krabbe et al. 1991; 750 km s^{-1}, Allen, Hyland, & Hillier 1990). The designations for the two previously known emission-line stars, q8 and q10, follow Moneti et al. (1994); the classifications for these stars are uncertain.

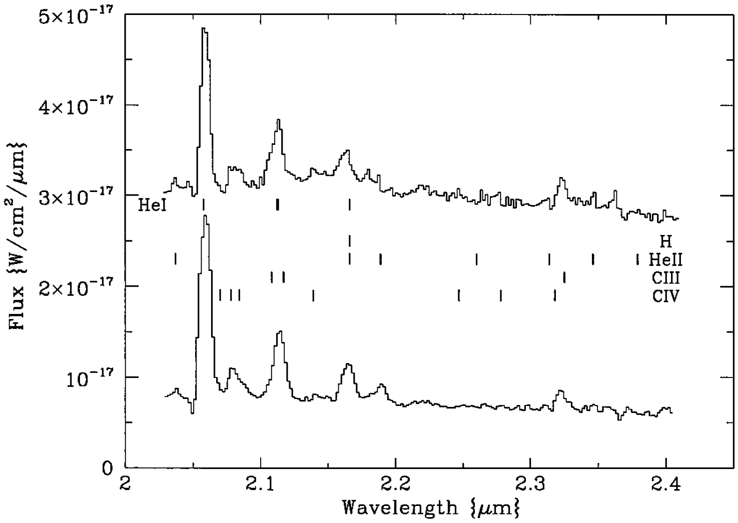

FIG. 1.—K-band spectrum ($R \approx 530$) of star 2 (*bottom*) and the WC9 star WR 121 (*top*). The intensity scale of the spectrum for WR 121 has been divided by 10. Single-pixel features near 2.189 μm and between 2.2 μm and 2.4 μm are not to be trusted. All spectra have been dereddened and flux-calibrated.

Using photometry from Williams, van der Hucht, & The (1987) and the extinction law from Rieke, Rieke, & Paul (1989), we calculate $A_K = 0.68$ and $M_K = -5.8$ for WR 121. We calculate log $(L/L_\odot) = 5.0$ assuming $M_v = -4.8$ (van der Hucht et al. 1988) and a bolometric correction $\mathrm{BC}_v = -3.0$ (Smith, Meynet, & Mermilliod 1994) for all WC9 stars. This implies a $\mathrm{BC}_K = -2.0$ for WR 121, a value consistent with other WC9 stars, given the assumed luminosity. WC9 stars are typically surrounded by dust and have $\overline{(H-K)_0} = 0.9 \pm 0.4$, where the error is the standard deviation for the sample in Williams et al. (1987). Using $(H-K)_0 = 0.9$ and $\mathrm{BC}_K = -2.0$ for star 2, we calculate $A_K = 2.1^{+0.8}_{-0.7}$, $M_K = -5.4^{+0.8}_{-0.7}$, and log $(L/L_\odot) = 4.9 \pm 0.3$. The extinction was verified by dereddening the spectrum of star 2 until it had the same slope as the dereddened spectrum of WR 121. We adopt this extinction (equivalent to $A_V = 19^{+7}_{-6}$) for the remaining sources; it is in the range given by Okuda et al. (1990) ($A_V = 16$–25), while Glass et al. (1990) give $A_V = 22$.

Stars within the LBV class have a wide range of BC_K: 0 to -3.5 according to Blum (1995a), so we use the arithmetic mean of their sample, $\mathrm{BC}_K = -1.4$, for star 3. Even assuming the most extreme cases for BC_K and A_K, we calculate log $(L/L_\odot) = 5.5$ to -7.5, comfortably in the range of luminosities for known LBVs (Humphreys 1989). We assume $\mathrm{BC}_K = -2.0$ for the remaining sources, and the errors are the same as those given above for star 2.

3. DISCUSSION

The spectra of star 2 and WR 121 are remarkably similar (see Fig. 1), and the presence of carbon is assured by the C IV line at 2.078 μm and the C IV/C III complex at 2.318/2.325 μm (Eenens, Williams, & Wade 1991). The emission line near 2.11 μm has a FWHM of 1440 km s^{-1}, more than would be expected from just the He I complex at 2.112/2.113 μm, and C III emission is a likely contributor to this blend. The displacements of the absorption components of the 2.058 μm line from line center are within the range of velocities observed for other WC9 stars (Eenens & Williams 1994). Maeder (1991) gives $M_{\mathrm{initial}} \gtrsim 50\ M_\odot$, $Z \gtrsim 0.02$, and $\tau_{\mathrm{age}} <$

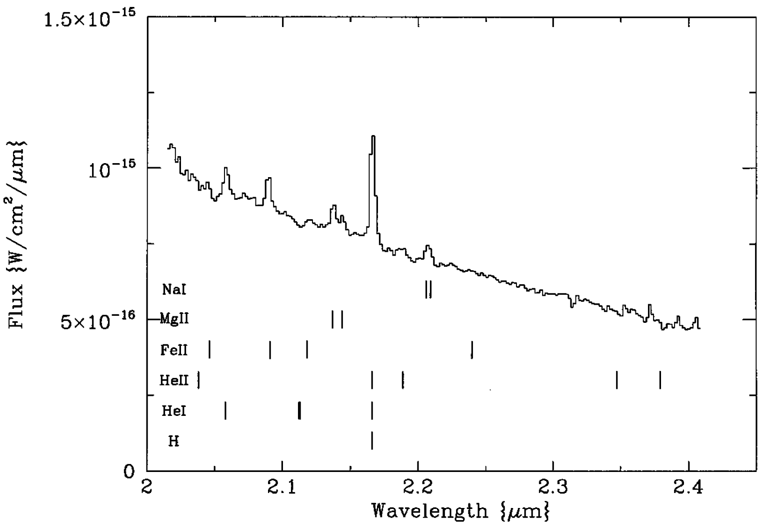

FIG. 2.—K-band spectrum of the proposed LBV candidate, star 3.

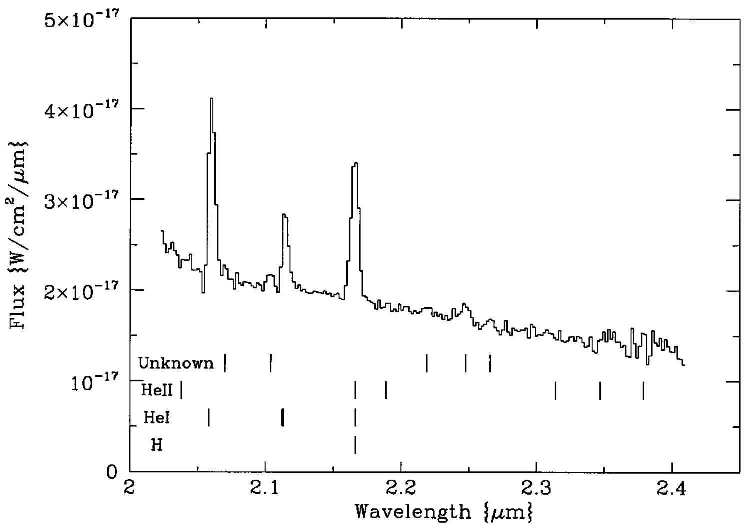

FIG. 3.—*K*-band spectrum of the proposed new WN9 star, star 1.

2.5×10^6 yr for WC9 stars. Blum, Sellgren, & DePoy (1995b) give an ionizing flux of $\gtrsim 5 \times 10^{48}$ photons s^{-1} for the new WC9 star they discovered in the central parsec of the Galaxy; we adopt this value as a lower limit.

The spectrum of star 3 is similar to the spectra of LBVs (see Fig. 2), notably HD 316285 (McGregor, Hyland, & Hillier 1988b), S Dor (Blum et al. 1995a), and η Car (Hamann et al. 1994). LBVs are generally believed to be evolved from main-sequence stars with $M_{\rm initial} > 40\ M_\odot$ (Maeder & Conti 1994). An absorption feature at $\approx 2.112\ \mu$m can be seen in star 3 and is believed to be due to the 2.112/2.113 He I complex; this feature also appears in absorption in B0 I stars (Hanson & Conti 1994) and in emission in η Car, HD 316285, and S Dor. The other identified lines of Na I, Mg II, Fe II, He II, He I, and H are variously seen in the spectra of these and other LBVs (Hamann et al. 1994; McGregor et al. 1988a, b; Blum et al. 1995a). The *H* band spectrum (not shown) shows additional iron lines at 1.644 μm, 1.688 μm, and 1.745 μm. Cotera et al. (1994) classify star 3 as a B[e] and offer a spectrum of He 3–1191 for comparison, but He 3–1191 has been reclassified as a proto–planetary nebula with $L < 10^3\ L_\odot$ (Le Bertre et al. 1989), while we calculate $L \approx 10^{6.3}\ L_\odot$ for star 3.

The LBV classification might provide a raison d'etre for the "Pistol" radio feature (Yusef-Zadeh & Morris 1987), G0.15−0.05, which might have been created by photoionized ejecta from past eruptive stages of the star (Lamers 1989; Davidson 1989). The Pistol requires $\approx 3.9 \times 10^{48}$ ionizing photons s^{-1} (Yusef-Zadeh, Morris, & van Gorkom 1989), and we calculate $\approx 3.4 \times 10^{48}\ s^{-1}$ (Panagia 1973) produced by the LBV candidate, assuming that its flux is similar to that of a B0 I star with $T_{\rm eff} \approx 30{,}000\ K$ (Humphreys 1989).

Star 1 (see Fig. 3) is similar to other Galactic center He emission-line stars (Krabbe et al. 1991) in that they all show emission lines of He I at 2.058 μm and Brγ; however, important distinctions remain. The spectrum is marked by He I emission lines, but $F_{2.058}/F_{\rm Br\gamma} \approx 0.9$ is much less than the typical values for the helium stars in the central cluster (e.g., IRS 16C has $F_{2.058}/F_{\rm Br\gamma} \approx 2.08$ and the AF star has $F_{2.058}/F_{\rm Br\gamma} \approx 2.88$ [Blum et al. 1995a]). On the other hand, $F_{2.112}/F_{\rm Br\gamma} \approx 0.4$ for the new star, whereas the Galactic center stars all have less than this value, except for IRS 13 and AHH NW (Blum et al. 1995a). Likewise, the other Quintuplet He emission-line stars, q8 and q10, barely have any detectable flux in the 2.112/2.113 μm complex, as measured in our own data (or see Geballe et al. 1994). The value of $\Delta V_{\rm FWHM}$ for the new star is somewhat greater than in q8 and q10; however, it is in the range measured for Galactic center stars (Krabbe et al. 1991). Star 1 is likely to be an evolved massive star like the Ofpe/WN9 or WN9 stars (Blum et al. 1995a). We tentatively identify star 1 as a WN9 type, although the classification is ambiguous. Maeder (1991) gives a minimum initial mass of 20 $M_\odot$ for WN-type stars having high metallicity, $Z > 0.04$. The relatively cool temperature for this star implies a low ionizing

TABLE 1

EMISSION-LINE STARS

Star	R.A.[a]	Decl.[a]	Type	K	$H-K$	M_K	log L[b]($L_\odot$)	ΔV[c] (km s^{-1})
Star 1	$17^h43^m3\overset{s}{.}6$	$-28°48'9\overset{''}{.}7$	WN9	10.5	1.9	−6.3	5.2	740
Star 2	$17^h43^m5\overset{s}{.}1$	$-28°49'11\overset{''}{.}6$	WC9	11.4	2.1	−5.4	4.9	1270
WR 121	$18^h41^m35\overset{s}{.}0$	$-03°51'4\overset{''}{.}0$	WC9	6.0	1.3	−5.8	5.0	1020
Star 3	$17^h43^m4\overset{s}{.}8$	$-28°48'56\overset{''}{.}9$	LBV	7.1	1.8	−9.7	6.3	710
q8	$17^h43^m5\overset{s}{.}5$	$-28°48'31\overset{''}{.}3$	?	8.8	1.8	−8.0	5.9	660
q10	$17^h43^m4\overset{s}{.}7$	$-28°48'30\overset{''}{.}5$	?	8.5	1.8	−8.3	6.0	<550

[a] Coordinates are for equinox 1950.

[b] See text for error statement.

[c] ΔV are measured FWHMs for the 2.058 μm He I line.

flux; for example, Najarro et al. (1994) calculate a rate of less than 10^{48} s^{-1} for the AF star at the Galactic center.

The "Sickle" H II region, G0.18−0.04 (Yusef-Zadeh, Morris, & Chance 1984) requires $\approx 3 \times 10^{50}$ ionizing photons s^{-1} (Harris et al. 1994). The net contribution from the five known emission-line stars is on the order of 10^{49} photons s^{-1}. While this rate is insufficient to ionize the Sickle, the total rate from the Quintuplet cluster may be much greater due to contributions from a probable population of accompanying O and B stars.

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