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INFRARED OBSERVATIONS OF R136, THE CENTRAL OBJECT OF THE 30 DORADUS NEBULA[1]

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ABSTRACT

Photometric observations of R136 in the J, H, K, and L infrared filters, made with the 3.6 m telescope of the European Southern Observatory, La Silla, Chile, reveal the presence of strong excess radiation produced by stellar wind. From model fitting of the infrared continuum we determine (a) the slope of the velocity variation with radius ($\gamma = 1.0^{+0.8}_{-1.1}$), ($b$) the mass loss rate $\dot{M} = 5.2 \times 10^{-4}$ $(v_0/200$ km s$^{-1})$ $M_\odot$ yr^{-1}, and (c) the stellar radius, which is determined in an implicit form as a function of the temperature. Adding information derived from the ionization of the 30 Doradus Nebula, we determine an ultraviolet brightness temperature in the range $(4.7–5.7) \times 10^4$ K and a total luminosity of $L(\text{R136}) = (6 \pm 2) \times 10^7$ $L_\odot$. This confirms that the stellar mass must exceed 2000 $M_\odot$. The comparable amounts of momentum carried by the wind and the radiation field indicate that the mass loss characteristics of R136 are closer to those of O-type stars rather than W-R stars. Combining the mass loss and luminosity values of R136 with those of galactic supergiants, we derive a $\dot{M}$-L relationship whose slope $\alpha = 1.1$ is coincident with that found for main-sequence stars.

Subject headings: nebulae: individual — stars: individual — stars: mass loss — stars: massive — stars: winds

I. INTRODUCTION

The unprecedented properties of R136 = HD 38268, the central object of the 30 Doradus Nebula, were recently noted by Feitzinger and Schlosser (1977). Further optical studies (Feitzinger and Schmidt-Kaler 1979; Feitzinger *et al.* 1980) revealed the presence of three components within 4″, the brightest and bluest of which, R136a, was suggested to contain a very massive (250–1000 $M_\odot$) star with temperature $T = (5.0–5.5) \times 10^4$ K.

From far-ultraviolet observations with the *International Ultraviolet Explorer* (*IUE*), Cassinelli, Mathis, and Savage (1981) estimate temperatures in excess of 5×10^4 K and luminosities $\gtrsim 5 \times 10^7$ $L_\odot$. The derived Eddington limit for the mass of a single object is 2×10^3 $M_\odot$, thus rendering R136a the most massive star known so far. Recent speckle observations by Meaburn *et al.* (1982) indicate that R136a has an angular diameter much smaller than 0″.02. Therefore, it is most probably a single object.

We secured near-infrared measurements of R136a in the course of our current study of the infrared emission of hot luminous stars in the Galaxy and in the Magellanic Clouds. In view of the interest raised by the extreme properties of this object, an early report of the results obtained seems worthwhile.

The observational results (§ II) allow us to determine the photospheric radius, the velocity field of the wind, and the mass loss rate (§ III). Combining these results with the ionization conditions in the 30 Doradus Nebula, we are able to estimate the brightness temperature at various wavelengths and the total luminosity of R136a and to confirm the high value of its mass (§ IV). The implications of the derived parameters for the general mass loss versus luminosity relationship are discussed in § V.

II. OBSERVATIONS

The photometric observations presented here were obtained during the nights of 1981 March 23 and 24 with the new infrared photometer at the 3.6 m telescope of the European Southern Observatory, La Silla, Chile. The photometer was equipped with a photovoltaic InSb detector. We used filters J ($\lambda_{\text{eff}} = 1.25$ μm), H ($\lambda_{\text{eff}} = 1.65$ μm), and K ($\lambda_{\text{eff}} = 2.2$ μm) in the ESO photometric system (Wamsteker 1980), and at longer wavelength, a filter L' centered on $\lambda_{\text{eff}} = 3.8$ μm, the measurements in which have been reduced to the standard L ($\lambda_{\text{eff}} = 3.6$ μm) at the cost of a slight loss of accuracy. No attempt to measure the star at 5 μm was made. The standard dual beam technique with nominal 10″ aperture and 20″ throw was adopted.

The problem of contamination of our measurements either by nebular radiation or by field stars must be considered. From multiaperture measurements in filter K of the region centered on R136 (Glass 1972), we estimate that both the underlying nebula and unresolved stars in the field contribute no more than a few hundredths of magnitude to the observed colors (see also McGregor and Hyland 1981). The components R136b and R136c (Feitzinger *et al.* 1980; Feitzinger and

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Schmidt-Kaler 1979), assumed to exhibit infrared colors pertaining to the spectral type indicated by their colors in the visible, contribute less than 2% to the observed magnitudes. The measured infrared colors might be substantially affected only by relatively luminous ($L > 10^4\ L_\odot$) cool stars (spectral type later than K), for whose presence, however, no evidence has been found so far. High angular resolution measurements are required in order to definitely exclude the presence of such stars in the immediate vicinity of R136a. In the following, no correction of the measured infrared colors for possible contamination will be made.

No variation within the uncertainties of the measurements was apparent between the two nights. Therefore, the observations, referred to the standard star BS 2015 ($J = 3.86$; $H = 3.74$; $K = 3.70$; $L = 3.67$), were combined to give the magnitudes reported in Table 1. The quoted errors correspond to statistical uncertainties only. While the $J-H$ and $H-K$ observed colors reported by McGregor and Hyland (1981) are in excellent agreement with ours, their magnitudes are ~ 0.3 brighter.

III. DISCUSSION

The observed energy distribution from 1.25 to 3.6 μm declines smoothly with wavelength, thus indicating the absence of strong lines contributing to the continuum flux. This is consistent (Williams 1982) with the attribution of the W-R spectrum to the nitrogen sequence. In particular, in the intermediate-resolution spectrophotometry of R136a from 2.1 to 2.45 μm (McGregor and Hyland 1981), the only discernible emission line occurs around 2.18 μm, with equivalent width of $\sim 8 \times 10^{-3}$ μm. This corresponds to a contribution of about 0.01 mag in the 0.6 μm wide photometric K band and, therefore, is completely negligible.

The reddening correction in the direction of the source appears somewhat problematic. From the measured $(b-v)$ color (Smith 1968), a color excess $E(B-V) = 0.29$ is derived assuming for R136a the mean intrinsic color $(b-v) = -0.21$ of an OB + WN star (Smith 1968); a value $E(B-V) = 0.39$ is obtained if the intrinsic color $(B-V) = -0.35$ of an extreme early O-type star is assumed. Israel and Koornneef (1979), on the basis of Walraven photometry with a number of different apertures (16″–62″), estimate $E(B-V) = 0.38 \pm 0.02$ (see also Koornneef and Mathis 1981). We note that measurements in large apertures may be affected by the presence of field stars in the crowded region around R136a. However, the observed trend of the measured $U-V$ color (Feitzinger *et al.* 1980) versus aperture indicates that, approaching R136a, reddening is not likely to increase.

TABLE 1

MAGNITUDES OF R136a

$J_{1.25\,\mu\mathrm{m}}$	$H_{1.65\,\mu\mathrm{m}}$	$K_{2.2\,\mu\mathrm{m}}$	$L_{3.6\,\mu\mathrm{m}}$
9.18 (0.04)	8.98 (0.04)	8.78 (0.04)	8.29 (0.06)

NOTE.—Statistical uncertainties are given in parentheses.

Reading from the map of Mills, Turtle, and Watkinson (1978), the Hβ/radio flux ratio at a position centered on R136a gives $A_{\mathrm{H}\beta} \approx 1.4$, implying $A_V \approx 1.2$. Assuming $E(B-V)$ within the limiting values of 0.29 and 0.39, the ratio of total to selective extinction $R = A_V/E(B-V)$ would turn out to be in the range 3.0–4.1. However, since the Hβ extinction is likely to refer to a longer column of absorbing material than is in front of R136, values closer to the lower limit of the interval should be more appropriate. Therefore, correction for extinction will be applied adopting the standard galactic value $R = 3.2$. In the infrared the relation $A_V : A_J : A_H : A_K : A_L = 1 : 0.28 : 0.16 : 0.12 : 0.05$ (e.g., Savage and Mathis 1979) is adopted.

The dereddened colors of R136a are very close to those of WN stars, both in the LMC and in our Galaxy (cf. Fig. 1). Among WN stars, single objects are definitely redder than O-type stars (both galactic and Magellanic), while binary systems (WN + O) have intermediate colors. The locus of binary systems in the two-color diagram is shown in Figure 1 for different values of the ratio of luminosity in the J band of the components (i.e., $L_J[\mathrm{WN}]/L_J[\mathrm{O}]$). This curve was computed adopting the mean colors $(J-H)_{\mathrm{WN}} = +0.15$, $(H-K)_{\mathrm{WN}} = +0.25$ and $(J-H)_{\mathrm{O}} = -0.10$, $(H-K)_{\mathrm{O}} = -0.05$. By comparison, the colors of R136a indicate that it is either a single object with dominant W-R spectral characteristics, or if binary, the W-R component is much brighter than the O-type component. Therefore, in the following, R136a will be considered a single star. A large infrared excess, relative to a blackbody radiator assumed to represent the photospheric continuum, is apparent (cf. Fig. 1), implying the presence of a stellar wind with high mass loss. The characteristics of the wind can be determined by fitting the infrared observations with theoretical spectra computed with the following assumptions:

1. R136a is a single object.
2. The wind is spherically symmetric. The velocity is described by the expression

$$v = v_0 (r/R_0)^\gamma \tag{1}$$

until the terminal velocity v_∞ is attained (v_0 being the initial velocity at the optical photospheric radius R_0).

3. Envelope gas is fully ionized and helium rich so that only the free-free emission process needs to be considered. The exact chemical composition is not crucial. In fact, the wind emission is a function of the product $(\dot{M}/v_0)(\bar{Z}^{1/2}/\mu_e)$, where $\bar{Z}$ is the average charge, and μ_e is the mean atomic weight per electron (Panagia and Felli 1975; Felli and Panagia 1982). In a fully ionized gas the ratio $\bar{Z}^{1/2}/\mu_e$ takes the values $1/\sqrt{2}$ and 1 for the extreme cases of pure helium and pure hydrogen, respectively. Therefore, changing the composition from pure He, as adopted here, to pure H would reduce the estimated value of $\dot{M}$ by only a factor $\sqrt{2}$.
4. The electron temperature in the wind is equal to the infrared radiation temperature of the photosphere: $T_e = T_{\mathrm{IR}}$.

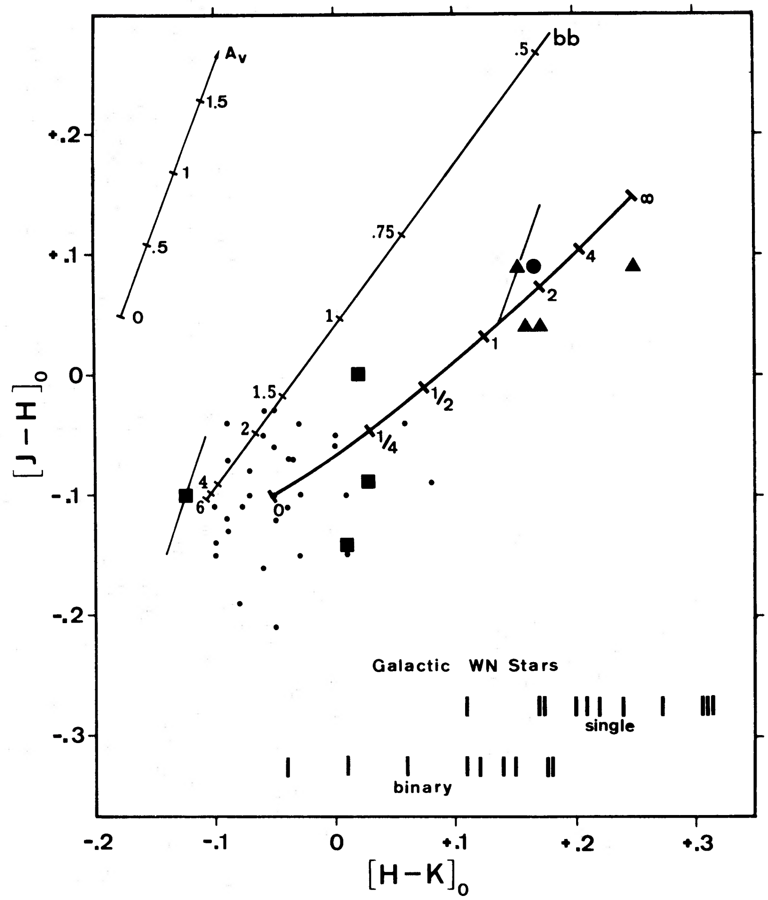

FIG. 1.—The intrinsic near-infrared colors of R136 (*filled circle*) are compared with those of WN stars in the Large Magellanic Cloud (*triangles*) (Panagia, Tanzi, and Tarenghi 1982*b*). The intrinsic colors of galactic (*small dots*) and Magellanic (*squares*) O-type stars are, respectively, from Tanzi, Tarenghi, and Panagia (1981) and from unpublished observations by the same authors.

The solid curve is the locus of binary systems (WN + O) with different ratios of the luminosity in the J band of the components. A straight line labeled *bb* represents the colors of the blackbody radiators at different temperatures (indicated in units of 10^4 K). $H-K$ colors of galactic WN stars (Allen, Swings, and Harvey 1972) are represented by vertical bars.

The parameters to be optimized are the stellar radius R_0, the velocity slope γ, and the ratio of the mass loss rate to the initial velocity $\dot{M}/v_0$. The temperature is left as a free parameter within the interval 2×10^4–10^5 K. A reddening correction as appropriate for each temperature is applied to the observed fluxes. For each temperature, a set of fitting parameters $R_0, \gamma, \dot{M}/v_0$ are determined with a minimum χ^2 fit of the dereddened broad-band fluxes.

The derived values of γ and $\dot{M}/v_0$ are insensitive to the adopted temperatures, whereas the photospheric radius is related to the temperature by the following condition on the stellar flux $\mathscr{F}_\lambda(J)$ in the J band:

$$4\pi R_{\rm IR}^2 \pi B_\lambda(1.25\ \mu{\rm m}, T) = 4\pi D^2 \mathscr{F}_\lambda(J) = 2.5 \times 10^{34}\ {\rm ergs\ s^{-1}\ \AA^{-1}}\ , \quad (2)$$

having assumed a distance $D = 55$ kpc to the LMC. Equation (2) can be more conveniently expressed as

$$R_{\rm IR}\, \rho(T) = 84.0\ R_\odot\ , \quad (3)$$

with

$$\rho(T) = \left[\frac{B_\lambda(1.25\ \mu{\rm m}, T)}{B_\lambda(1.25\ \mu{\rm m}, 6 \times 10^4\ {\rm K})}\right]^{1/2} = 0.460\left[\exp\left(\frac{1.1511}{T_4}\right) - 1\right]^{-1/2}, \quad (4)$$

and $T_4 = 10^{-4} T_{\rm IR}$. In Figure 2 the best fitting spectra obtained for $T_{\rm IR} = 2.4 \times 10^4$ K and $T_{\rm IR} = 5.7 \times 10^4$ K are displayed, together with the experimental points.

Acceptable fits (such as obtained for $\chi^2 < \chi^2_{\rm min} + 3.5$, which is appropriate for a three-parameter fitting; e.g., Avni 1976) are obtained for values of γ in the interval -0.1 to $+1.8$. The corresponding range of variability of the fitting parameters $\dot{M}/v_0$ and R_0 are shown in Figure 3, for the assumed values $v_0 = 200$ km

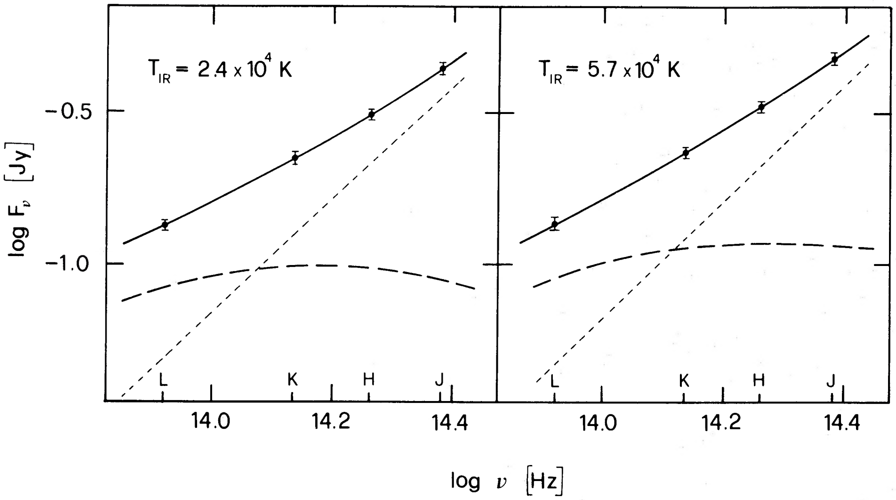

FIG. 2.—The best fitting spectra (*solid curves*) obtained for $T = 2.4 \times 10^4$ K (*left*) and $T = 5.7 \times 10^4$ K (*right*). Short-dashed and long-dashed curves represent the photospheric blackbody continuum and the emission from the stellar wind, respectively.

s^{-1} and $T_0 = 5.7 \times 10^4$ K. The overall uncertainty is about a factor of 2, either direction, on $\dot{M}$ and about $\pm 10\%$ on R_0. The uncertainty can be substantially reduced by constraints on γ. The analysis of a number of W-R stars suggests values of γ around unity in most cases (Panagia, Tanzi, and Tarenghi 1982*a*).

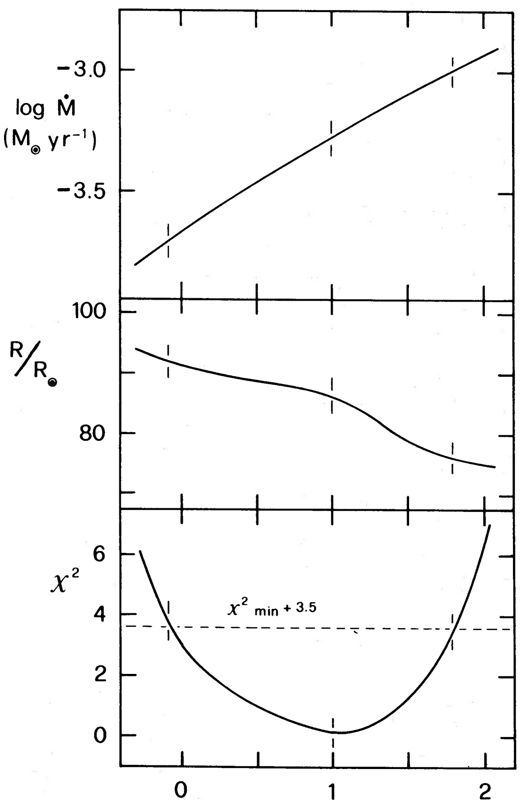

FIG. 3.—The mass loss rate, the stellar radius, and the χ^2 value as a function of the velocity slope for $v_0 = 200$ km s^{-1} and $T = 5.7 \times 10^4$ K. The values corresponding to the minimum $\chi^2_{min} = 0.1$ and those for $\chi^2 = \chi^2_{min} + 3.5$ are marked by vertical bars.

The minimum χ^2 values of the parameters and their range, to a 1 σ significance level, are summarized in Table 2. Note that the wide uncertainty interval for $\dot{M}/v_0$ is mostly due to the uncertainty in γ rather than being inherent to the ratio $\dot{M}/v_0$. In fact, for any *fixed* value of γ the 1 σ uncertainty in $\dot{M}/v_0$ is only $\pm 9\%$.

In order to determine the mass loss rate, the value of v_0 is needed. It cannot be derived from our data. Following Panagia and Felli (1982), Panagia, Tanzi, and Tarenghi (1982*b*), and Felli and Panagia (1982), a value of $v_0 = 200$ km s^{-1} can be taken as appropriate for WN stars to within a factor of 2. Since the optical line profiles in R136a are also indicative of a comparably high initial velocity (100–200 km s^{-1}; Feitzinger and Schlosser 1977), we can confidently adopt such a value. The mass loss rate is then estimated to be

$$\dot{M} = 5.2 \times 10^{-4} \left(\frac{v_0}{200 \text{ km s}^{-1}}\right) M_\odot \text{ yr}^{-1} . \quad (5)$$

This value is in close agreement with the independent estimate $\dot{M} \approx 7 \times 10^{-4}$ $M_\odot$ yr^{-1} obtained by Ebbets and Conti (1982) from a measurement of Hα line intensity. Such a high mass loss rate provides evidence for a very high stellar mass. In fact, for a stellar lifetime

TABLE 2

VALUES AND RANGES OF THE FITTING PARAMETERS FOR AN ADOPTED DISTANCE OF D(LMC) = 55 KPC

Parameter	Best Fitting Values ($\chi^2 = 0.1$)	Range ($\chi^2 < 3.6$)
γ	1.0	−0.1 to 1.8
$R_0\,\rho(T)^a\,(R_\odot)$	84	77 to 93
$\frac{\dot{M}}{v_0}\left(\frac{10^{-4}\,M_\odot\,\text{yr}^{-1}}{10^2\,\text{km s}^{-1}}\right)$	2.6	1.0 to 5.2

[a] The quantity $\rho(T)$ is defined in eq. (4).

equal to, or greater than, 10^6 yr the shed mass is of $\sim 500\ M_\odot$, at least, which implies an even higher stellar mass, say $M > 10^3\ M_\odot$.

IV. THE PROPERTIES OF R136a

As mentioned before, the fit of the IR spectrum leads to a relationship between the photospheric radius and the temperature. The ionization balance of the 30 Doradus Nebula, assumed to be mainly ionized by R136a, provides an additional relationship between the radius and the temperature of the star. The number of the Lyman continuum photons required to ionize the nebula is between 5×10^{51} and 10^{52} photons s^{-1} (McGee, Brooks, and Batchelor 1972; Mills, Turtle, and Watkinsons 1978), and R136a is likely to be responsible for at least 50% of the total ionization. We adopt 5×10^{51} photons s^{-1} as the most appropriate value, to within a factor of 2, for the photons contributed by R136a and derive the corresponding R-T relationship (see Fig. 4). Its crossing with the curve derived from infrared data determines the values of R and T reported in the second column of Table 3, which refer to the assumption $T_{UV} = T_{IR}$ and $R_{UV} = R_{IR}$.

On the other hand, it is well known that in W-R stars the color temperature increases with frequency. In particular, Panagia and Felli (1982) show that optical brightness temperatures around $(2.5\text{–}3.5) \times 10^4$ K may correspond to temperatures from 4×10^4 to 5×10^4 in the UV domain. Therefore, in the infrared an approximate relationship $T_{UV} \approx 1.5 T_{IR}$ (± 20%) may be expected. However, since R136a is not a typical W-R star (as far as luminosity, mass, and possibly chemical composition are concerned), this may not apply exactly.

As for the radius, we note that in a helium-rich atmosphere the opacity in the Lyman continuum, being mostly due to excited He and He^+, may not be much

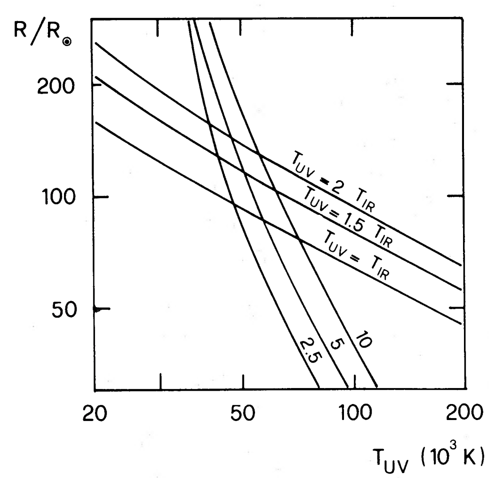

FIG. 4.—The photospheric radius as a function of the ultraviolet brightness temperature. The curves with shallower slope are obtained from model fitting of the infrared spectrum and are marked with the adopted T_{UV}-T_{IR} relationship. The steeper curves are derived from the ionization conditions of the 30 Doradus Nebula. The label attached to each curve denotes the flux of ionizing photons provided by R136a, in units of 10^{51} photons s^{-1}.

TABLE 3

DERIVED PARAMETERS OF R136a

Parameter	$T_{UV} = T_{IR}$	$T_{UV} = 1.5 T_{IR}$	$T_{UV} = 2 T_{IR}$
T_{UV} (10^4 K)..........	5.7 ± 1.1	5.1 ± 1.0	4.7 ± 0.9
T_{IR} (10^4 K)..........	5.7 ± 1.1	3.4 ± 0.7	2.3 ± 0.5
R_0 ($R_\odot$)..............	8.6 ± 9	116 ± 12	146 ± 15
L ($10^7\ L_\odot$)...........	7.1 ± 2.1	5.8 ± 1.7	5.2 ± 1.5
$E(B-V)$.............	0.37	0.30	0.24
m_V	9.59 ± 0.08	9.49 ± 0.12	9.40 ± 0.16

higher than in the optical and in the near-infrared. Therefore, it may well be that $R_{UV} \approx R_{IR}$. If a systematic difference exists, it is $R_{UV} < R_{IR}$, which would make the UV temperature even higher than T_{IR}. Table 3 shows the values of both the Lyman continuum and the infrared temperatures and the radius derived assuming $R_{UV} = R_{IR}$ and considering three cases: $T_{UV} = T_{IR}$, $T_{UV} = 1.5 T_{IR}$, and $T_{UV} = 2 T_{IR}$. The uncertainties quoted for each parameter in Table 3 result from those in the R-T relationship derived from the infrared data and from the ionization conditions, respectively. The range of T_{UV} and L for the three cases considered is smaller than the intrinsic uncertainty. For this reason and on the grounds that T_{UV} is likely to be higher than T_{IR}, it seems justified to adopt a total luminosity

$$L(\text{R136a}) = 6 \pm 2 \times 10^7\ L_\odot\ . \quad (6)$$

This is much higher than the luminosity of any known star and supports the suggestion that R136a is a supermassive star with $M > 2000\ M_\odot$ (Cassinelli, Mathis, and Savage 1981).

Table 3 reports also the visual magnitudes of R136a predicted assuming that a blackbody curve with $T = T_{IR}$ can describe the stellar emission in the optical. Reddening corrections appropriate to each temperature have been applied (row 5 of Table 3). In the range of temperature considered, the predicted visual magnitudes are very close to the observed values ($m_v = 9.47$, Westerlund and Smith 1964; $m_v = 9.42$, van den Bergh and Hagen 1968; $m_v = 9.44$, Smith 1968). The small systematic difference between theory and observations may be ascribed to the contribution of field stars and nebular emission in the visible range. Good agreement is obtained also in the ultraviolet.

As an example, the spectrum obtained with the best fit parameters, in the case $T_{UV} = T_{IR} = 5.7 \times 10^4$ K, is compared with the observations in Figure 5. The theoretical spectrum has been reddened according to the extinction law by Koornneef and Code (1981) in the ultraviolet and according to the standard galactic law at longer wavelength (Savage and Mathis 1979, and references therein). The infrared data are from the present work. The fluxes in the UV region are derived from Koornneef and Mathis (1981) *IUE* observations sampled every 100 Å. Allowance for the nebular contribution in the observing slot of *IUE* has been made by subtracting a flux of 2×10^{-13} ergs cm^{-2} s^{-1} $Å^{-1}$ (see Koornneef and Mathis 1981). An overall uncertainty of ± 10% has

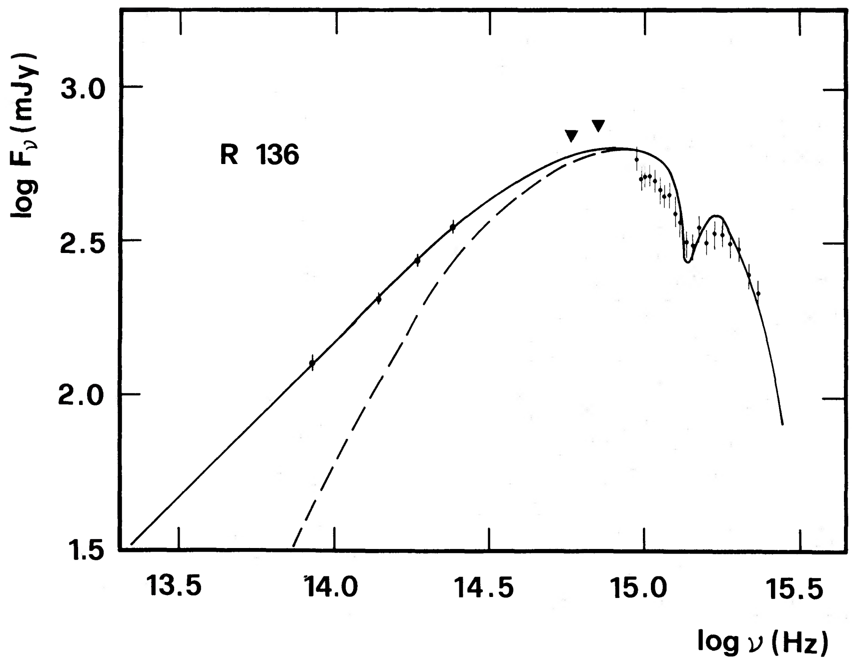

FIG. 5.—The computed spectrum for $T_{IR} = 5.7 \times 10^4$ K. The dashed curve represents the photospheric radiation, whereas the solid curve corresponds to the total (i.e., photospheric + wind) emission. The theoretical spectrum has been reddened adopting $E(B-V) = 0.37$. The observational data are: infrared, present paper; optical, Smith (1968); ultraviolet, adapted from Koornneef and Mathis (1981).

been attributed to the UV data as a result of combined uncertainties in the *IUE* photometry, reading accuracy, and estimate of nebular contribution. The representation of the observed spectrum is generally quite good, the deviations between theoretical and observed data being usually smaller than 10%. Adopting lower temperatures, the quality of the fit turns out to be lower ($\sim$20%) as long as the LMC reddening curve is adopted. On the other hand, if the mean galactic law is adopted, the situation is reversed: better fits (deviation $\lesssim$10%) are obtained for temperatures close to 2.5×10^4 K, which, however, appears somewhat too low.

We note that each of the temperatures derived for R136a is lower than that expected from detailed stellar model calculations (e.g., Nomoto and Sugimoto 1974), which, for example, would predict an effective temperature of $T_{\rm eff} \approx 84{,}000$ K for a star of 1000 $M_\odot$. However, one must consider that the high mass loss rate makes the envelope of R136a optically thick so that the photospheric radius can be larger than that in the absence of mass loss. Therefore, the effective temperature can be lower than that estimated for a plane-parallel atmosphere, as customarily assumed in stellar model calculations.

With our estimate of $\dot{M}$ and L, and adopting a terminal velocity $v_\infty = 3500$ km s^{-1} (Cassinelli, Mathis, and Savage 1981), we find that the ratio of the momentum carried by the wind to that of the stellar radiation is

$$\dot{M} v_\infty c/L = 1.3 \ . \qquad (7)$$

This value is intermediate between that of early O-type stars ($\sim$0.5, Panagia and Macchetto 1982) and that of "normal" WN stars ($\sim$16, Barlow, Smith, and Willis 1981), being, however, much closer to the former than to the latter. This suggests that R136a, although exhibiting WN features in the visible spectrum, is likely to be just a very massive star with a strong wind rather than a proper W-R star. Recent spectroscopic observations in the near-infrared by Vreux, Dennefeld, and Andrillat (1982) also indicate that R136a does not exhibit clear W-R characteristics, being more similar to the most luminous galactic O stars.

V. THE MASS LOSS VERSUS LUMINOSITY RELATIONSHIP

The values of $\dot{M}$ and L derived for R136a could provide interesting clues to the $\dot{M}$ versus L relationship for early-type stars. From various analyses of observational data on galactic stars a relationship in the form

$$\dot{M} = A(L/L_\odot)^\alpha \qquad (8)$$

is derived, α ranging from 1.1 (Barlow and Cohen 1977) to 1.8 (Abbott *et al.* 1980). The most recent determinations we are aware of is that by Abbott, Bieging, and Churchwell (1981), derived from accurate radio measurements of a dozen OB stars:

$$\dot{M}_{\rm ABC} = 8.9 \times 10^{-6} \left(\frac{L}{10^6 L_\odot}\right)^{1.56} M_\odot \ {\rm yr}^{-1} \ . \qquad (9)$$

On the other hand, a best fit to the Abbott, Bieging, and Churchwell (1981) data *plus the values* found for R136a gives

$$\dot{M}_{\rm general} = 9.3 \times 10^{-6} \left(\frac{L}{10^6 L_\odot}\right)^{1.12} M_\odot \ {\rm yr}^{-1} \ . \qquad (10)$$

This relationship yields essentially the same mass loss rate for galactic supergiants as equation (9), but it has a much shallower slope, very similar to that obtained by fitting the accurate and rich data of Gathier, Lamers, and Snow (1981) for main-sequence stars: $\alpha = 1.1 \pm 0.1$.

This result is significant as long as comparing R136a with galactic early-type supergiants is justified. We believe this to be the case because we have shown in § IV that R136a is a hot star whose only peculiarity is its very high mass. Moreover, the lower metal abundance in the Large Magellanic Cloud (LMC), compared with our Galaxy, appears to play a negligible role since galactic and LMC OB and WN stars are found to exhibit comparable infrared excesses and mass loss rates (Panagia, Tanzi, and Tarenghi 1982*b*; Bruhweiler, Parsons, and Wray 1982).

Therefore, we conclude that a slope close to 1.1 is of general validity for all classes of early-type stars, whereas the proportionality constant A (cf. eq. [8]) is a function of the evolutionary stage, being highest for supergiants and lowest for main-sequence stars (Tanzi, Tarenghi, and Panagia 1981).

VI. CONCLUSIONS

We have made infrared photometric observations of R136a in the J, H, K, and L bands. The dereddened colors are much redder than expected for the photospheric emission, revealing the presence of an excess radiation produced by a stellar wind. The observed energy distribution has been interpreted in terms of two components: (*a*) a blackbody emitter representing the photospheric continuum and (*b*) emission from an accelerated wind which is assumed to be spherically symmetric, isothermal, and made of pure helium. By model fitting we have determined

1. The slope of the velocity field $\gamma = 1.0^{+0.8}_{-1.1}$.
2. The mass loss rate, which, for an initial velocity of 200 km s^{-1}, is found to be $\dot{M} = 5.2 \times 10^{-4}\ M_\odot$ yr^{-1}.
3. The stellar radius, which is determined as a function of the temperature (eqs. [3] and [4]).

With the additional radius-temperature relationship derived from the ionization conditions of the 30 Doradus Nebula, we have determined for R136a an ultraviolet brightness temperature between 4.7×10^4 and 5.7×10^4 K and a total luminosity of $L(\text{R136a}) = (6 \pm 2) \times 10^7\ L_\odot$. These results confirm that the mass of R136a is definitely greater than 2000 $M_\odot$. We have also found that the ratio of the momentum carried by the wind to that available in the radiation field is much closer to values typical for O-type stars than to values typical for W-R stars. This suggests that R136a is just a very massive star with strong mass loss rather than a bona fide WN star.

For this reason and considering also that the metal abundance appears not to affect appreciably the mass loss rate of early-type stars, the $\dot{M}$ and L values of R136a are combined with those of galactic supergiants in order to derive a $\dot{M}-L$ relationship over a wide luminosity interval. The slope of the correlation is found to be ~ 1.1, coincident with that determined for galactic main-sequence stars.

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