THE ASTROPHYSICAL JOURNAL, 283:560–565, 1984 August 15

PROPERTIES OF R136a AS DERIVED FROM ITS OPTICAL LIGHT DISTRIBUTION

YOU-HUA CHU,[1] JOSEPH P. CASSINELLI, AND MARK G. WOLFIRE[1]
Washburn Observatory, University of Wisconsin–Madison
Received 1983 October 10; accepted 1984 February 28

ABSTRACT

We have used short exposure 4 m prime focus plates taken with interference filters centered on blue continuum 4765 Å, He II 4686 line, red continuum 6485 Å, and Hα line to study the light distribution within R136a. R136a contains a bright component and several fainter components superposed on an extended background. The brightest component, unresolved under sub-arcsec seeing condition, contributes about 37% of the total light from a 3″ diameter aperture. Combining the optical and UV information, we find this brightest component R136a_1 may be a single star with a mass of $\sim 750\ M_{\odot}$ with a brightness of six HD 93129A or 20 O3 V stars, or it could be a cluster of such stars. In either case, R136a_1 supplies no more than one-half of the ionization of the 30 Doradus nebula.

Subject headings: clusters: open — nebulae: individual — stars: early-type

I. INTRODUCTION

R136 (HD 38268) is the luminous central object of the 30 Doradus nebula in the Large Magellanic Cloud (LMC). Its bluest and brightest component, R136a, has been interpreted as a *supermassive star* with a mass of approximately 2000 $M_{\odot}$, based on its unusual ultraviolet spectral properties and the assumption that it is responsible for most of the ionization of the 30 Dor nebula (Feitzinger *et al.* 1980; Cassinelli, Mathis, and Savage 1981, hereafter CMS; Savage *et al.* 1983). On the other hand, R136a has also been argued to be the *core of a dense cluster*, since the integrated light distribution from 0.2 to 22 pc radius centered on R136a is similar to that of a globular cluster (Moffat and Seggewiss 1983), and the optical spectrum of R136a can be synthesized by its nearby early-type stars (Melnick 1983).

The supermassive star interpretation relies on the assumption that R136a is a point source dominating the UV flux from a 3″ aperture. The arguments for the core-of-a-cluster nature presented by Moffat and Seggewiss (1983) is a necessary but not sufficient condition for R136a to be a normal unresolved core of the cluster NGC 2070. Melnick's (1983) spatially resolved spectra of R136a demonstrate a composite nature; however, the proportions of light contribution from a point source and the background contamination could not be determined, and the existence of a dominating supermassive star could not be excluded. Moreover, when deriving the brightness distribution within R136, Moffat and Seggewiss have used the wrong spatial scale in Figure 6 of Feitzinger *et al.* (1980). The horizontal scale of their Figure 2 should be reduced by a factor of 1.45, i.e., their 1″.0 is actually 0″.7. As a result of this correction and the effects of atmospheric seeing, the brightness in R136a is more peaked to the center than indicated in their Figures 3*a* and 3*b*, and the claimed similarity in brightness distribution between R136 and the core of a globular cluster therefore needs serious reconsideration. In order to discriminate whether there is a supermassive star, it is essential to examine the detailed content of R136a, and to separate the brightest component from the extended complicated background.

There have been two independent speckle interferometry observations of R136a; unfortunately, their results are conflicting. Meaburn *et al.* (1982) find one primary component with an angular diameter $< 0''.02$, and a few secondary components within 0″.9 from the primary. The brightest secondary component is 0″.8 from the primary and 81 times fainter. In the meanwhile Weigelt (1983) finds five components within a 2″ × 2″ area. Besides the primary component a_1, there are two components (a_2 and a_3) at 0″.46 and 0″.1 away and both 1–2 mag fainter, and two more fainter components at about 1″ away from a_1. By contrast, the micrometer double star measurements of a_1 and a_2 (Innes 1927; Worley 1984) have been relatively consistent. The existing measurements are summarized in Table 1, and they seem to support at least the a_1 and a_2 components of Weigelt's results.

We have taken short exposure 4 m prime focus plates of R136 in four interference filter passbands under sub-arcsec seeing conditions at Cerro Tololo Inter-American Observatory (CTIO). In this paper we report the color and light distribution within R136a based on our new plate material and discuss the constraints it sets on the nature of R136a.

II. OBSERVATIONS AND DATA REDUCTION

We obtained a series of prime focus plates of R136 on the 4 m telescope at CTIO during two observing runs in 1983 January and February. See Table 2 for the plate information.

TABLE 1

MICROMETER DOUBLE STAR MEASUREMENTS OF R136a[a]

Position[b] Angle (1)	Separation (″) (2)	Brightness Difference (mag) (3)	References (4)
215°..........	0.5	1–2	Innes 1927
168°..........	0.9	5	
110°..........	1.3	4	
118°..........	2.6	4	
221°..........	0.47	1	Worley 1984

[a] These are the positions and brightness of the fainter components relative to the primary component.

[b] The position angles are measured counterclockwise from the north.

[1] Visiting Astronomer, Cerro Tololo Inter-American Observatory, operated by the AURA, Inc., under a contract with the National Science Foundation.

TABLE 2

4 m Prime Focus Plates[a]

Filter[b] (1)	Plate Number (2)	Exposure Time (s) (3)	Date of Observation (4)	Remarks (5)
4680 Å..........	5978	240	1983 Jan 27	
	5979	60	1983 Jan 27	
	5980	2–10	1983 Jan 27	13 exposures
	5998	2–10	1983 Feb 25	40 exposures
	5999	60	1983 Feb 25	
	6009	30	1983 Feb 26	
	6010	180	1983 Feb 26	
4765 Å..........	5974	240	1983 Jan 26	
	5975	60	1983 Jan 26	
	5981	2–10	1983 Jan 27	15 exposures
	6000	60	1983 Feb 25	
	6001	2–10	1983 Feb 25	40 exposures
	6011	30	1983 Feb 26	
	6012	180	1983 Feb 26	
6485 Å..........	6004	150	1983 Feb 25	
	6008	240	1983 Feb 26	
6565 Å..........	6003	2–10	1983 Feb 25	40 exposures
	6006	30	1983 Feb 26	
	6007	30	1983 Feb 26	

[a] Baked IIIa-J plates were used for the 4680 and 4765 filters, and baked IIIa-F plates were used for the 6485 and 6565 filters.

[b] The FWHM, equivalent width, and peak transmission of these filters are: (65 Å, 41 Å, 64%), (70 Å, 43 Å, 64%), (25 Å, 17 Å, 68%), and (120 Å, 76 Å, 65%), respectively.

Our new observations are characterized by their short exposure time and the use of narrow interference filters. The exposure time is 30 sec to 4 min for the single exposure plates, and 2 to 10 sec for each exposure on the multiple exposure plates. The interference filters we used were centered on (1) blue continuum "b" at 4765 Å, (2) He II λ4686 line, (3) red continuum "r" at 6485 Å, and (4) Hα λ6563 line. These filters were chosen to allow us to compare the plates to detect the He II and Hα line emission objects and determine the colors of different components. Note that the blue continuum and the red continuum passbands do not contain any nebular emission lines; therefore, the 30 Dor nebula is effectively filtered out.

The plates were digitized with the PDS machine at MADRAF (Midwestern Astronomical Data Reduction and Analysis Facility). The sampling aperture size is 10×10 μm and the sampling step size is 5×5 μm. The plate scale is approximately 18″.6 per mm, and 5 μm corresponds to 0″.093. The density maps are then converted to relative intensity maps using the calibration provided by the sensitometer spots on the plates. The new calibration table for wedge 117 published on the CTIO Newsletter Number 3 was used in constructing the characteristic curves.

Since the angular extent of R136a is only about 4″, the detectibility of any small-scale structures within R136a is a strong function of the seeing. It is important to monitor the seeing condition. We use the star R131, which is about 3′ from R136, as a reference star to calibrate both the flux and the seeing *for each exposure.* R131 is a B9 I star with $V = 10.24$ mag, $B-V = 0.35$ mag, and $U-B = -0.38$ mag (Rousseau *et al.* 1978). We find that most of the plates were taken under subarcsec seeing conditions, since the star profiles of R131 have FWHM about 0″.7 to 0″.9.

III. RESULTS

We have plotted contour maps (Fig. 1) of R136 in the four passbands to examine its light distribution. Using the profile of R131 as a point spread function, we have decomposed R136a into a_1, a_2, and background components.

a) The Light Distribution in R136

In the contour maps (Fig. 1), R136 is clearly resolved into a, b, and c components, as reported earlier by Feitzinger *et al.* (1980). R136a apparently has a bright component and several fainter components superposed on an extended background (3″ × 4″). The shapes of the inner three contours are consistent with the micrometer measurements of a_1 and a_2. We are unable to resolve the component a_3, which is only 0″.1 from a_1 (Weigelt 1983).

Farther away from a_1, there are two components about 2–3 mag fainter at positions (1″.2, 80°) and (1″.5, 160°), a much fainter component at (1″.6, 10°), and a still fainter component at (2″.6, 320°). The last faint component is only detected on the longer exposure plates. Since these components and the extended background are detected in passbands that exclude nebular emission lines, the light sources must be stellar, not nebular.

The components we have detected do not agree completely with the components measured by Innes (1927). Although micrometer measurements of double stars can acquire 0″.1 accuracy easily, we find larger errors in Innes's measurements. For example, his component at (118°, 2″.64) from a_1 should have been resolved into R136b and R136c at similar position angles but 2″.2 and 3″.4 from a_1. We have verified the distances from a_1 to b and c on other plates taken on the Yale 1 m telescope at CTIO. Therefore, we believe our results are right.

R136c, considerably brighter in the He II and Hα passbands than the corresponding continuum passbands, is obviously a W-R star. R136c has been recently classified WN7 spectroscopically by Melnick (1983), who also suggests a possibly similar spectral type for R136b. However, our data do not

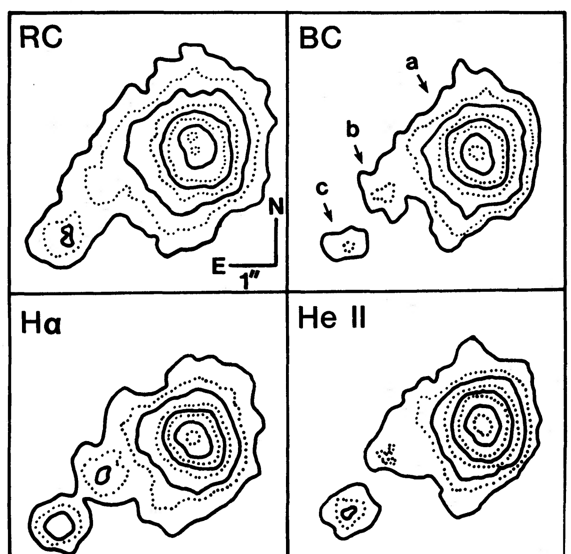

FIG. 1.—Surface brightness contour maps of R136 in four passbands: red continuum 6485 Å, Hα 6563 line, blue continuum 4765 Å, He II 4765 line. The maps have been normalized to the peak intensities, and the contour levels are 0.9, 0.7, 0.5, 0.4, 0.3, 0.2, 0.15, and 0.1, respectively. The pixel size is 0″.093. The contours in the c-component show the quality of the images. In the red continuum map the breaking-up of the innermost contour in the a and c components demonstrate a poor point spread function. Unfortunately, it is the only image in the red continuum we have obtained.

support the W-R nature of R136b, unless it is a weak-lined transitional type WN/Of star. WN7 stars have the weakest He II λ4686 line among the WN stars (Conti, Leep, and Perry 1983). If R136b were a typical WN star, its He II line flux would have been detected as easily as R136c.

b) *The Brightness and Color of R136*a_1 *and the Background*

For simplicity, we have assumed that R136a consists of two unresolved components (a_1 and a_2) and a background component. Since Weigelt's (1983) a_1 and a_3 are too close to be resolved in our data, the apparent brightness and color we derive for a_1 are actually for ($a_1 + a_3$).

We used the two-dimensional surface brightness profile of R131 as point spread function, multiplied it by a guessed brightness ratio of R136a_1 to R131, and subtracted it from the intensity map of R136 at the estimated position of a_1. The best ratio was selected when the residual map showed smoothly varying background. Then we repeated the process for a_2. The location of a_2 relative to a_1 is adopted from the micrometer measurements. This technique is rather subjective. The ratio of a_2:a_1 may be uncertain by 50%, depending on the estimated position of a_1. However, the brightness of a_1 can be relatively accurately determined to 10%. This decomposition process is made quick and easy with the capability of displaying the false color isophotes of each map on a TV system (Grinnell). The decomposition of a blue continuum map is demonstrated in Figures 2*a* and 2*b* by two cuts along and perpendicular to a_1–a_2.

R136a_1 is 0.42 and 0.33 times as bright as R131 in the *b* and *r* passbands, respectively. R136a_2 is probably 1.5 mag fainter than R136a_1. If there is indeed another point source a_3 at 0.″1 from a_1, then the true brightness of a_1 is reduced from the apparent values in Table 3 by approximately a factor of $(1 + x)$, where x is the brightness ratio of a_3 to a_1.

We have integrated the light within a 3″-diameter area centered on R136a_1. The total light is 1.14 and 0.92 times the brightness of R131 in the *b* and *r* passbands, respectively. The brightest unresolved component a_1 only contributes about 37% of the total light within a 3″ aperture.

TABLE 3

SUMMARY OF THE RESULTS

Passband (1)	a_1:R131 (2)	a_1:a_2[a] (3)	(3″):R131 (4)
b—4765 Å	0.42:1	1:0.3	1.14:1
He II—4686 Å	0.54:1	1:0.3	1.34:1
r—6485 Å	0.33:1	...	0.92:1
Hα—6563 Å	0.44:1	1:0.4	1.12:1

[a] This ratio may be uncertain by 50%.

R131 is a B9 I star with $V = 10.24$ mag and $(B-V) = 0.35$ mag. Its intrinsic flux ratio F_λ(4700 Å)/F_λ(6500 Å) is about 2.5. Adopting an extinction $A_V = 1.2$ mag for R136 (Savage *et al.* 1983; see Fitzpatrick and Savage 1984 for a detailed discussion of extinction in 30 Dor region), we derived intrinsic flux ratios F_λ(4700 Å)/F_λ(6500 Å) of about 3.5 ± 0.2 and 3.2 ± 0.2 for R136a_1 and the 3″ background, respectively. This flux ratio is about 3.6 for hot stars with $T_{\rm eff} = 35{,}000$ to 45,000 K (Kurucz 1979), and is 2.4 for a WN5 star (Smith and Kuhi 1981). Therefore, the colors of R136a_1 and the background are consistent with those of hot stars.

The brightness of the components relative to R131 in these four passbands is summarized in Table 3. Their energy distributions in the *b* and *r* passbands are plotted in Figure 3, together with the UV spectra from Savage *et al.* (1983). We may interpolate between *b* and *r* passbands to obtain *V* magnitudes. The derived *V* magnitudes for a_1 component and the total light within 3″ are 11.2 mag and 10.1 mag, respectively. The corresponding M_V are -8.6 mag and -9.7 mag.

c) *The Equivalent Width and Origin of the* He II *and* Hα *Lines*

The intrinsic equivalent width (EW) of the stellar emission lines can be approximated by

$$[(f_L/f_C) - 1] \times (\Delta\lambda)_L/R_L ,$$

where f_L and f_C are the flux ratios of the object to R131 in the line and continuum passbands and $(\Delta\lambda)_L$ and R_L are the equiv-

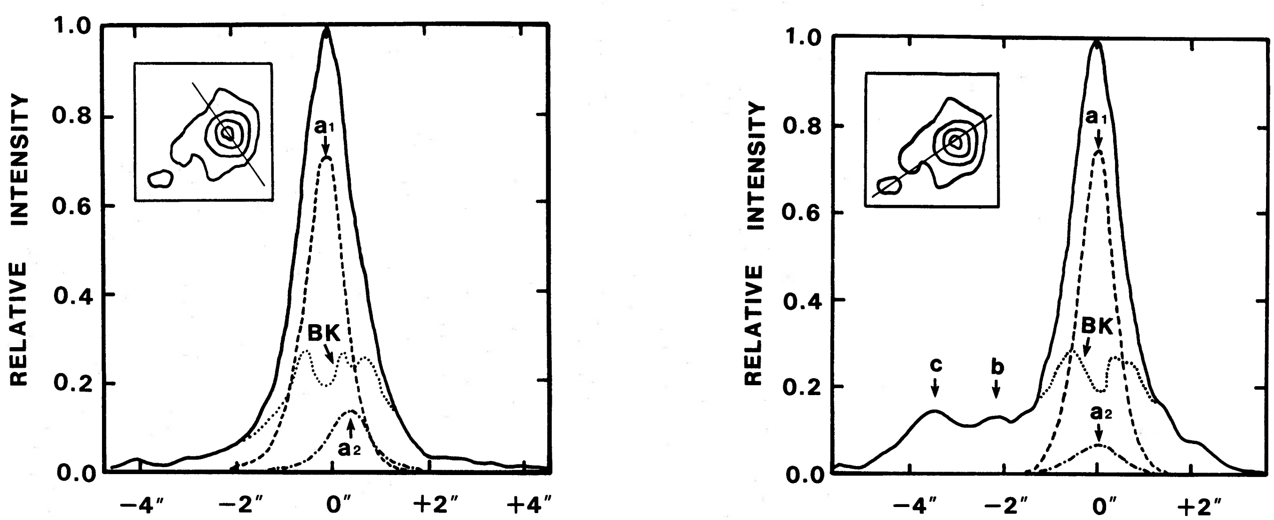

FIG. 2*a* FIG. 2*b*

FIG. 2.—Intensity profiles of R136a along and perpendicular to the line a_1–a_2. A line is drawn on the contour map to show the orientation and position of the cut. The contribution from each component is labeled on the curves.

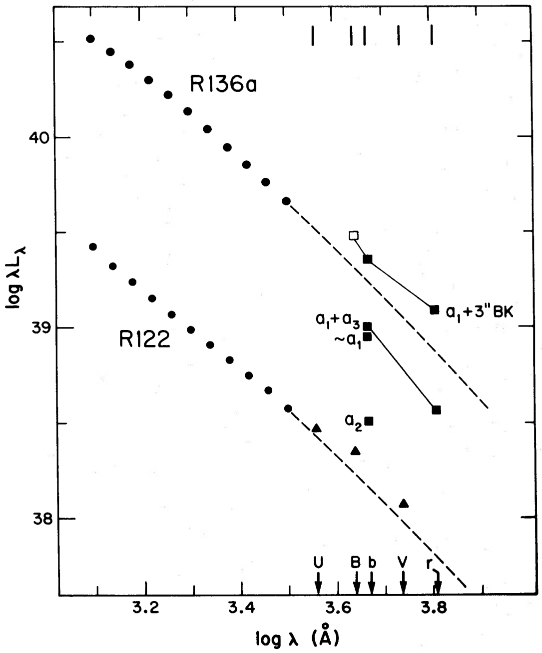

FIG. 3.—Luminosity level of R136a and R122. R122 is the most luminous O3 star in the LMC and is as luminous as the galactic O3 star HD 93129A. The UV luminosity of R136a and R122 (●) and the optical luminosity of R122 (▲) are adopted from Savage *et al.* (1983). The new optical luminosities of R136a derived in this paper are represented by squares: ■—photographic data, □—CCD data. The dashed lines (– – –) are "arbitrary" extrapolations from the UV luminosity, for purpose no more than eye-guiding. The effective wavelengths of the standard UBV and our *b* and *r* passbands are indicated along the horizontal axis. The unit for the vertical axis λL_λ is ergs per second.

alent width and peak transmission of the filter centered on the line. The filter characteristics can be found in the note to Table 2 and the fluxes in Table 3.

The total He II λ4686 and Hα line fluxes from the central 3" area are both about 0.2 times the integrated flux of R131 in the corresponding line passbands. If we assume the line fluxes have a similar spatial distribution with the continuum flux in the 3" area, then we derive equivalent widths of $EW = 11$ and 25 Å for the He II and Hα lines, respectively. These values are in good agreement with the spectroscopic data reported by Ebbets and Conti (1982). However, the assumption that the spatial distribution of the line flux is similar to that of the continuum is not correct. While blinking *b* and He II plates taken with similar exposures, we have found the line emission concentrated near the center, instead of spreading out. The most likely candidates for emitting the lines are therefore a_1, a_2, and a_3.

If the line fluxes are from exclusively one star, we may derive a lower limit on the line equivalent width by assuming the line fluxes are from the brightest star. From the brightest unresolved component ($a_1 + a_3$), we derive a lower limit of 30 Å for EW(He II) and 70 Å for EW(Hα). These values greatly exceed the values for the earliest type O stars, for which EW(He II) < 7 Å and EW(Hα) < 10 Å (Conti and Frost 1977). The spectral features of R136a are consistent with those of WN5 stars (Ebbets and Conti 1982), so let us now assume that the line emitting star is a WN5 star. Suppose, for example, that a_2 is the WN5 star and responsible for *all* of the line emission. Its EW(He II) would be about 100 Å and EW(Hα) would be about 150 Å. These values are within the acceptable range for WN5 stars (Conti, Leep, and Perry 1983). Yet a problem would exist because WN5 stars have a spectral energy distribution that is flatter than that of normal O stars, so a_2 would be as bright as ($a_1 + a_3$) in the Hα passband and this much brightening is not observed. That is, one does not detect a sizable shift in the spatial distribution of the emission toward a_2 at Hα wavelength. Therefore, we may exclude the possibility that a_2 is a WN5 star providing all the line fluxes. The line emitting star is probably in the ($a_1 + a_3$) component.

Of course, there might be more than one star emitting the He II and Hα lines, and the line fluxes ought to be divided among several stars. Since our spatial resolution limited imagery does not provide further information, we will not enumerate any further possible configurations of line flux distribution.

IV. COMPARISON WITH OTHER DATA

Since there are no other photometric data of R136a in the passbands we used, we have interpolated the fluxes at 4700 Å and 6500 Å to obtain the V-magnitudes. The total light within 3" centered on R136a has a derived V magnitude of $\sim$10.1 mag, and the brightest unresolved component R136a_1 has a derived $V = 11.2$ mag.

Schmidt-Kaler and Feitzinger (1981) have integrated the total light within 2".2 centered on R136a from the V-contour map in Figure 6 of Feitzinger *et al.* (1980) and estimated a V magnitude $\sim$10.77 mag. The aperture size alone cannot account for this difference in V magnitude. We suspect the major portion of this difference has arisen from the difference in seeing conditions and calibration procedure. We have calibrated the flux against R131, adopting a V magnitude of 10.24 (Rousseau *et al.* 1978), while they have calibrated the flux against a photoelectric measurement of R136 with a 7" aperture (Feitzinger *et al.* 1980), which is 9.98 mag.

Wood and Seitzer (1983) have taken a 4 m prime focus CCD image of R136 in B passband. The integrated light within 3" centered on R136a is 1.7 mag brighter than that of R145 ($B = 12.13$ mag, Rousseau *et al.* 1978). The B magnitude of the 3" area is therefore 10.4 mag. The integrated light within 3" aperture in B, b, and r passbands is plotted in Figure 3.

As to the spatial distribution of the light within R136, we find our contour maps (Fig. 1) show similar characteristics with the contour maps by Feitzinger *et al.* (1980). Moffat and Seggewiss (1983) fitted the latter V-isophotes of R136a by an exponential curve. Using this fit and a correction of their spatial scale discussed earlier, we find a FWHM of 1".4 for R136a. This corrected value is in good agreement with 1".2 ± 0.1 from our data. Note that the FWHM of the image of R131, a single star, is about 0".9 ± 0.1 in our data. The seeing for Feitzinger *et al.*'s data was assumed to be 1".5 (Moffat and Seggewiss 1983). However, judging from the good match to our values above, their FWHM of the seeing must have been substantially better than the 1".5 that they quote as being the typical seeing during their observing run.

V. DISCUSSION

A major goal of the observations here has been to determine the fraction of the light of R136a that originates from the dominant component of R136a_1. The results of this study are summarized in Figure 3 which shows the energy distribution of R136a from UV through optical wavelengths. For the UV, we sketch the luminosity level derived by Savage *et al.* (1983) from *IUE* observations obtained with the 3" aperture. We have determined the monochromatic luminosity within 3" aperture

TABLE 4

SINGLE STAR PROPERTIES OF R136a_1
(assuming $\lambda L_\lambda = 1.0 \times 10^{39}$ ergs s^{-1} at 4700 Å)

Effective Temperature (K)	Model[a]	F_ν at $\lambda 4700$	No. of H Ionizing Photons s^{-1}	Star Radius ($R_\odot$)	Luminosity ($L_\odot$)	Eddington Mass ($M_\odot$)	Total Star Mass[b] ($M_\odot$)
40,000..........	HM 302	2.92×10^{-3}	2.4×10^{50}	53.0	6.4×10^6	170.	370.
50,000..........	HM 305	3.69×10^{-3}	7.6×10^{50}	47.1	1.2×10^7	340.	513.
60,000..........	HM 300	4.41×10^{-3}	1.5×10^{51}	43.1	2.1×10^7	580.	750.
75,000..........	HM 310	5.48×10^{-3}	3.1×10^{51}	38.7	4.2×10^7	1140.	1290.
90,000..........	HM 308	6.96×10^{-3}	5.1×10^{51}	34.4	6.9×10^7	1880.	2010.
50,555..........	EXT	5.13×10^{-3}	1.3×10^{51}	40.0	9.2×10^6	250.	400.
94,681..........	EXT	6.32×10^{-3}	2.0×10^{51}	36.0	9.2×10^7	2520.	2660.
50,000..........	BB	4.53×10^{-3}	6.9×10^{50}	42.6	1.0×10^7	270.	430.
60,000..........	BB	5.75×10^{-3}	1.2×10^{51}	37.8	1.6×10^7	450.	590.
75,000..........	BB	7.59×10^{-3}	2.4×10^{51}	32.9	3.0×10^7	830.	950.
90,000..........	BB	9.45×10^{-3}	3.8×10^{51}	29.5	5.0×10^7	1380.	1490.

[a] Models are those of Hummer and Mihalas (1970), Cassinelli (1971), or blackbodies.
[b] Conversion from Eddington Mass to Total Stellar Mass is made using the empirical wind relation $v_\infty = 3v_{esc} = 3(2G(M - M_{ed})/R_*)^{1/2}$ with $v_\infty = 3500$ km s^{-1}.

in the optical range and find it to be a factor of 2.5 larger than our final estimate of R136a_1. This might be used to estimate the background correction to the *IUE* results, but the relative UV to optical flux of the background is not known.

The nature of R136a has been discussed in lengthy detail by Savage *et al.* (1983). In the following we will only discuss the necessary modifications caused by our additional spatial information for the supermassive star and cluster models.

a) A Single Supermassive Star Model

The stellar properties of R136a as a single star have been recalculated and presented in Table 4, analogous to Table 1 in CMS and Table 4 in Savage *et al.* (1983). Here we use our blue magnitude *b* estimates and use models (Hummer-Mihalas, extended, and blackbody) to infer stellar radii, ionizing fluxes, etc. As in the previous papers (CMS; Savage *et al.* 1983), the Hummer-Mihalas models are chosen simply for convenience because monochromatic fluxes F_λ and hydrogen and helium ionizing fluxes are provided for a wide range in stellar effective temperature. Single supermassive stars may have extended atmospheres or nonstandard atmospheric structures so extended atmosphere models (Cassinelli 1971) and blackbody models are also considered in Table 4.

The temperature of R136a_1 can be independently estimated from stellar interior modeling and nebular diagnostics. CMS derived a temperature of $\sim$63,000 K for a hydrogen burning zero-age main-sequence supermassive star using the polytropic theory of Hoyle and Fowler (1963). As a very massive star evolves off the main sequence its temperature increases (Maeder 1980). To diagnose the temperature of the exciting source of a nebula, Mathis (1982) uses the abundance ratios of O^+/O and S^+/S^{++} in the nebula, and finds that 30 Dor nebula needs exciting stars with $T_{eff} > 45,000$ K. However, the numerical value of T_{eff} depends on which model atmosphere physics (i.e., line blanketing, LTE, etc.) is used. His further analysis indicates that observations are consistent with, but do not require, an even higher temperature (Savage *et al.* 1983). A much lower temperature of 38,000 K has been derived by Lequeux *et al.* (1981); however, they only used the nebular line ratio of [O III]/Hβ, which alone could not diagnose stellar effective temperatures unambiguously (Mathis 1982). Although Dufour (1983) has cautioned that the nebular data (Peimbert and Torres-Peimbert 1974) used in this diagnosis were taken at spots near ionization fronts, its effect is probably negligible because more than 70% of oxygen is doubly ionized there.

If R136a_1 should have a temperature $\sim$60,000 K as expected from stellar interior theory, we see from Table 4 that a mass of $\sim 750 \pm 200\ M_\odot$ would be deduced and that it provides about 1.5×10^{51} H ionizing photons/sec or only about 30% of the 5×10^{51} H ionizing photons/sec required by the 30 Dor nebula. For the star to account for all of the ionization of the nebula its temperature would have to be $\sim$90,000 K. This temperature is inconsistent with the nebular diagnostic, and the star is unlikely to be so hot. Our new mass estimate of $\sim 750\ M_\odot$ is far below the initial estimate of $\sim 2000\ M_\odot$ in CMS but nonetheless impressive. This decrease has arisen from the improved estimate of the relative light contributions from R136a_1 and the background within 3″ aperture.

Walborn (1984) argues that stars, other than those in R136, in 30 Dor could account for more than $\frac{1}{2}$ of the ionization. Massey and Hutchings (1983) argue on the other hand that R136 is responsible for a major fraction of the ionization of 30 Dor. If we use the brightness in the *b* band of R136 within 3″ of $\lambda L_\lambda \sim 2.9 \times 10^{39}$ ergs/sec at 4700 Å, then from Table 4 we find that the R136 object could account for 2.2×10^{51} ionizations/sec, assuming a mean temperature of 50,000 K. This is still only $\frac{1}{2}$ of the required ionizing luminosity, suggesting that stars outside the R136 complex are needed to explain the ionization of 30 Dor, as proposed by Walborn (1984).

b) Cluster Model

Since R136a_1 is unresolved with a 0″.8 seeing, its physical dimension must be < 0″.4, which corresponds to about 0.1 pc in the LMC. R136a_1 has an M_V of ~ -8.6 mag. Using this dimension derived from our data, R136a is not very dense compared to some other objects as a cluster of stars. It has been demonstrated (Rosa, Melnick, and Grosbøl 1984; Moffat and Seggewiss 1983) that the cluster in the galactic giant H II region NGC 3603 has higher concentration of brightness. However, these demonstrations involve deliberate degradation of the spatial resolution. The results might be different if information with the highest possible spatial resolution is used. The core of NGC 3603 is resolved into at least six components—HD 97950ABCDEF, and the 0″.6 double AB is estimated to be

9.6 mag in V magnitude, meaning an M_V of -8.7 mag within a dimension of 0.02 pc (Walborn 1984). If the a_1 component of R136a in our decomposition process only consists of the a_1 and a_3 components of Weigelt's speckle results, then the real brightest point source would have an M_V of -8.4 mag within the diffraction-limited resolution of 0″.03, corresponding to 0.008 pc. Obviously, more accurate high resolution photometry is needed for further meaningful comparison of spatial densities.

The stellar content of R136a is different from that of HD 97950. The former is dominated by O3 type features both in UV (Savage *et al.* 1983) and near-IR (Vreux, Dennefeld, and Andrillat 1982) spectra, while the latter is dominated by O5 stars (Walborn 1982*a*; Moffat 1983). Assuming that R136a_1 consists of O3 stars only, we may estimate how many O3 stars are needed. The most luminous O3 star, HD 93129A, has an M_V of -6.6 mag, and an average O3 V star about -5.4 mag (Walborn 1982*b*). Therefore, R136a_1 may contain six to 20 O3 stars. Considering the rarity of O3 stars (only eight are found in the Galaxy and two in the LMC, Walborn 1982*b*), R136a_1 would have an incredible concentration of O3 stars. The highest concentration of O3 stars known in our Galaxy is in Trumpler 14 and 16—six O3 stars in a projected dimension of ~ 10 pc, and the densest system of O3 stars there (HD 93128/HD 93129AB) has a projected dimension of about 0.3 pc (Walborn 1982*b*; Feinstein, Marraco, and Muzzio 1973). Melnick (1983) has shown a large number of O3 stars in the vicinity of R136a. It might be common that giant H II regions do contain large number of O3 stars.

In summary: We have further constrained the limits on the properties of R136. Its visually brightest unresolved component a_1 may be a single star with a mass of $\sim 750\ M_\odot$ with a brightness of six HD 93129A or 20 O3 V stars, or it could be a cluster of such stars. In either case, R136a_1 supplies no more than $\frac{1}{2}$ of the ionization of the 30 Dor nebula. Further photometry with high spatial resolution (speckle observations, for example) at shorter wavelengths should be pursued to set tighter constraints on the nature of R136a.

We wish to thank Drs. P. Osmer and V. Blanco and the CTIO staff for making the observations possible and enjoyable. We also thank Dr. A. Moffat for reading the manuscript critically and make useful comments. We have benefited from enlightening discussions with Drs. E. Fitzpatrick, R. Kennicutt, P. Massey, J. Mathis, J. Melnick, M. Rosa, B. Savage, W. Seggewiss, N. Walborn, and G. Weigelt on both R136 and 30 Dor nebula. Y. H. C. is especially grateful to the MADRAF users for tolerating her monopolyzing the PDS and Grinnell, and the graduate students for listening to her endless gripes during the tedious data reduction. This research has been supported by grant AST 8118814 from the National Science Foundation and grant NAGW283 from the National Aeronautics and Space Administration.

REFERENCES

Cassinelli, J. P. 1971, *Ap. Letters*, **8**, 105.
Cassinelli, J. P., Mathis, J. S., and Savage, B. D. 1981, *Science*, **212**, 1497, (CMS).
Conti, P. S., and Frost, S. A. 1977, *Ap. J.*, **212**, 728.
Conti, P. S., Leep, E. M., and Perry, D. N. 1983, *Ap. J.*, **268**, 228.
Dufour, R. 1983, private communication.
Ebbets, D. C., and Conti, P. S. 1982, *Ap. J.*, **263**, 108.
Feinstein, A., Marraco, H. G., and Muzzio, J. C. 1973, *Astr. Ap. Suppl.*, **12**, 331.
Feitzinger, J. V., Schlosser, W., Schmidt-Kaler, Th., and Winkler, C. 1980, *Astr. Ap.*, **84**, 50.
Fitzpatrick, E. L., and Savage, B. D. 1984, *Ap. J.*, **279**, 578.
Hoyle, F., and Fowler, W. A. 1963, *M.N.R.A.S.*, **125**, 169.
Hummer, D. G., and Mihalas, D. 1970, JILA Report No. 101 (Boulder, University of Colorado).
Innes, R. T. A. 1927, *Southern Double Star Catalog*, (Johannesburg: Union Observatory).
Kurucz, R. L. 1979, *Ap. J. Suppl.*, **40**, 1.
Lequeux, J., Maucherat-Joubert, M., Deharveng, J. M., and Kunth, D. 1981, *Astr. Ap.*, **103**, 305.
Maeder, A. 1980, *Astr. Ap.*, **92**, 101.
Massey, P., and Hutchings, J. B. 1983, *Ap. J.*, **275**, 578.
Mathis, J. S. 1982, *Ap. J.*, **261**, 195.
Meaburn, J., Hebden, J. C., Morgan, B. L., and Vine, H. 1982, *M.N.R.A.S.*, **200**, 1P.
Melnick, J. 1983, *Messenger*, No. 32, p. 11.
Moffat, A. F. J. 1983, *Astr. Ap.*, **124**, 273.
Moffat, A. F. J., and Seggewiss, W. 1983, *Astr. Ap.*, **125**, 83.
Peimbert, M., and Torres-Peimbert, S. 1974, *Ap. J.*, **193**, 327.
Rosa, M., Melnick, J., and Grosbøl, P. 1984, in *IAU Symposium 108, Structure and Evolution of the Magellanic Clouds*, ed. S. van den Bergh and K. S. de Boer (Dordrecht: Reidel), p. 257.
Rousseau, J., Martin, N., Prevot, L., Rebeirot, E., Robin, A., and Brunet, J. P. 1978, *Astr. Ap. Suppl.*, **31**, 243.
Savage, B. D., Fitzpatrick, E. L., Cassinelli, J. P., and Ebbets, D. C. 1983, *Ap. J.*, **273**, 597.
Schmidt-Kaler, Th., and Feitzinger, J. V. 1981, in *The Most Massive Stars*, ed. S. D'Odorico, D. Baade, and K. Kjar (Munchen: European Southern Observatory), p. 105.
Smith, L. F., and Kuhi, L. V. 1981, *JILA Report*, No. 117, p. 1.
Vreux, J. M., Dennefeld, M., and Andrillat, Y. 1982, *Astr. Ap.*, **113**, L10.
Walborn, N. R. 1982*a*, *A.J.*, **87**, 1300.
Walborn, N. R. 1982*b*, *Ap. J. (Letters)*, **254**, L15.
Walborn, N. R. 1984, in *IAU Symposium 108, Structure and Evolution of the Magellanic Clouds*, ed. S. van den Bergh and K. S. de Boer (Dordrecht: Reidel), p. 243.
Weigelt, G. 1983, private communication.
Wood, J., and Seitzer, P. 1983, private communication.
Worley, C. E. 1984, *Ap. J. (Letters)*, **278**, L109.

JOSEPH P. CASSINELLI, YOU-HUA CHU, and MARK G. WOLFIRE: Washburn Observatory, University of Wisconsin, 475 North Charter Street, Madison, WI 53706