Central Object of the 30 Doradus Nebula, a Supermassive Star
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Reports

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Abstract. *R136 (HD 38268) is the central object of the 30 Doradus Nebula, a giant region of ionized hydrogen in the Large Magellanic Cloud. Observations of R136 at low and high spectral resolution with the International Ultraviolet Explorer reveal a peculiar hot object with a massive stellar wind. An outflow speed of 3500 kilometers per second and a temperature of approximately 60,000 K are indicated by the spectra. The bulk of the observed ultraviolet radiation must come from R136a, the brightest and bluest component of R136. Its absolute visual magnitude and observed temperature imply a luminosity about 10^8 times that of the sun. Most of the ionizations produced in 30 Doradus are provided by this peculiar object. If R136a is a dense cluster of very hot stars, about 30 stars of classes O3 and WN3 exist in a region estimated to have a diameter of less than 0.1 parsec. This is inconsistent with the ultraviolet line spectrum and the evidence for optical variability. An alternative interpretation of the observations is that the radiation from R136a is dominated by a single superluminous object with the following approximate properties: luminosity and temperature as given above, a radius 100 times that of the sun, a mass 2500 times that of the sun, and a loss rate of $10^{-3.5}$ solar masses per year. Model interior calculations for hydrogen-burning stars are consistent with these parameters. Such stars, however, are expected to be unstable, and this may account for the massive stellar wind.*

The well-studied 30 Doradus or Tarantula Nebula in the Large Magellanic Cloud (LMC) is the most luminous H II (ionized hydrogen) region in the local group of galaxies (*1*). Radio continuum measurements (*2*) show that the nebula is ionized by the equivalent of 100 type O5 stars. The search for the source of this ionizing radiation has recently focused on the unusual object R136 (HD 38268) in the center of the nebula. From ground-based optical studies, Feitzinger *et al.* (*3*) suggested that the brightest, bluest component of R136, known as R136a, might contain a very massive star that produces most of the ionizing radiation.

We have obtained new information on the nature of R136a from an analysis of low- and high-resolution spectra obtained by the International Ultraviolet Explorer (IUE). These new data provide an estimate of the temperature of R136a. This temperature, when combined with ground-based estimates of the absolute visual magnitude (M_V), implies a luminosity for R136a of about 10^8 times the solar luminosity ($L_\odot$) and establishes that the nebula is primarily ionized by this object. A further analysis of the existing data implies that the radiation from R136a is probably dominated by that from a single object of mass $M \sim 2000$ to 4000 times the mass of the sun ($M_\odot$).

Ultraviolet observations. The IUE was used to obtain the ultraviolet (UV) spectra of R136 listed in Table 1. The exposures were made with large (10 by 20 arc sec) and small (3 arc sec) apertures, at low ($\approx$ 7 Å) and high ($\approx$ 0.1 Å) resolution, with the short (1170 to 2000 Å) and long (1900 to 3100 Å) wavelength cameras (*4, 5*).

Figure 1 illustrates a low-resolution, small-aperture spectrum of R136. The fluxes plotted do not allow for the light loss at the small aperture, which usually amounts to a factor of 2 for a point source. The continuum flux is strongly affected by the presence of interstellar dust, which produces the depression near 2200 Å and the decline below 1500 Å (*6*). Interstellar lines are identified below the spectrum; stellar lines are marked above. The most noteworthy stellar features are the P Cygni lines of C IV (1548 and 1551 Å), He II (1640 Å), and N IV (1718 Å). The P Cygni N V doublet (1238 and 1242 Å) is present but is strongly affected on the shortward side by interstellar Lyman α absorption. The stellar Si IV doublet (1394 and 1403 Å) is weak, most of the absorption being interstellar as inferred from the high-resolution data. The feature near 1370 Å is a blend of stellar O V (1371 Å) and LMC interstellar Ni II (1370 Å). The overall appearance of the stellar line spectrum at low resolution is intermediate between that of galactic WN3 and WN4 stars observed by IUE (*7*). Thus a UV classification of R136 implies a hotter object than the visual classification, OB(n) + WN5 + A(B), of Walborn (*8*). Since the UV and visual data contain different amounts of contamination from other stars, this result is not surprising.

The large-aperture, high-resolution spectrum of R136 (image SWP 8002), which we will emphasize in our discussion, is of much higher quality than the small-aperture, high-resolution spectra (images SWP 2766 and SWP 7989). Figure 2 shows the large-aperture spectrum of R136 in the Si IV (1394 and 1403 Å), He II (1640 Å), and C IV (1548 and 1551 Å) regions. The Si IV region of the spectrum is dominated by the interstellar

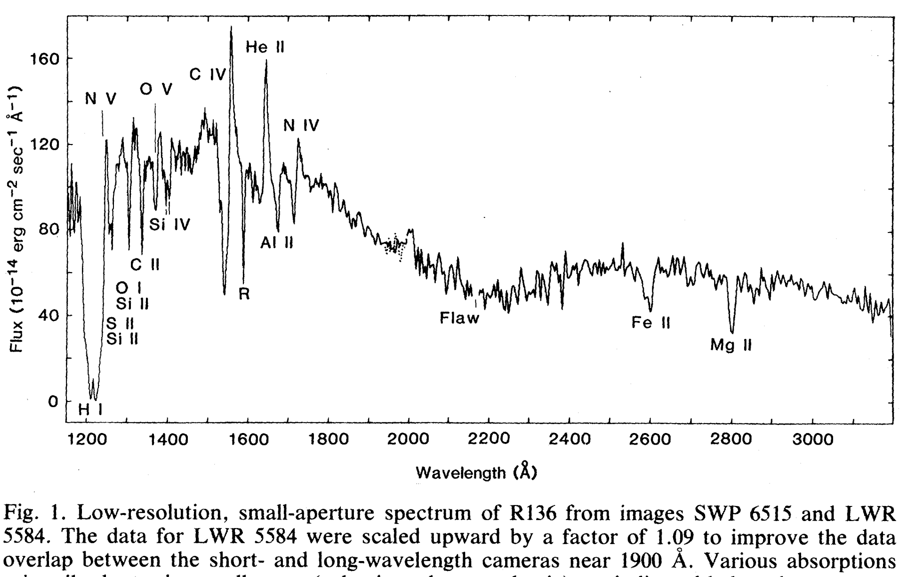

Fig. 1. Low-resolution, small-aperture spectrum of R136 from images SWP 6515 and LWR 5584. The data for LWR 5584 were scaled upward by a factor of 1.09 to improve the data overlap between the short- and long-wavelength cameras near 1900 Å. Various absorptions primarily due to interstellar gas (galactic and extragalactic) are indicated below the spectrum (*9*). The stellar features are marked above the spectrum. Interstellar dust in the LMC produces the depression near 2200 Å and the decline in flux below 1500 Å (*6*).

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(galactic and extragalactic) components (*9*). A stellar Si IV P Cygni feature is not readily apparent, although weak Si IV absorption may exist shortward of the 1394 Å line. Uncertainties in the background and echelle blaze corrections introduce undulations in the continua of IUE high-dispersion spectra for wavelengths $\lambda \lesssim 1500$ Å. Near 1383 Å an unidentified emission feature may be present. This feature could be of instrumental origin, but inspection of the low-resolution spectra suggests that it is real. The R136 He II emission resembles that found for other Wolf-Rayet stars with an unidentified emission component appearing inside the P Cygni absorption near 1630 Å (*7*). The P Cygni profile of C IV is unusual in that it is very broad and flat-bottomed with an intensity level of ~ 40 percent of the continuum. For C IV, He II, and N IV, we infer outflow speeds (v_{edge}) of approximately 3500, 3300, and 2100 km sec^{-1}. A strong N V (1238 and 1242 Å) P Cygni profile is seen in the high-dispersion spectrum. However, the short-wavelength part of the line lies near the bottom of an exceedingly strong interstellar Lyman α line. The value 3500 km sec^{-1} for the C IV line probably refers to the wind terminal speed for the R136 object.

An important consideration is the UV spatial extent of R136. Intensity tracings perpendicular to the dispersion across the high- and low-resolution, large-aperture spectra show that the far-UV ($\lambda \approx 1500$ Å) spatial extent is broader than that of comparison point sources. However, on comparing profile areas we find that the spatial extension observed for R136 contains about 30 percent of the detected large-aperture UV radiation, and most of this contamination comes from stars located ~ 8 arc sec northwest of R136a. These stars are identified as stars 3 and 4 in the isophote plots of Feitzinger *et al.* (*3*). We conclude that ~ 70 percent of the radiation recorded in the large-aperture, high-dispersion spectrum of R136 shown in Fig. 2 is from a "point source," which for our data extraction scheme implies an angular diameter of $\lesssim 2$ arc sec. The small-aperture spectra we obtained mostly refer to R136a alone. The small-aperture, high-dispersion spectrum (SWP 2766) generally confirms the results obtained from the large-aperture spectrum. In particular, similar terminal velocities are inferred for the various ions. The C IV P Cygni line is again filled in at about the 40 percent level. However, between ~ 2300 and ~ 2700 km sec^{-1} the data suggest somewhat less filling in. The other small-aperture spectrum (SWP 7989) is of very low quality; apparently R136a was not properly centered on the aperture.

Interpretation of spectra. The spatially extended nature of R136 and its resolution into components a, b, and c (*3*) suggest that many stars are present in a cluster. However, the UV measurements are dominated by radiation from R136a. Therefore the IUE spectra may provide the key to deciding whether the radiation from R136a is from a compact cluster ($\lesssim 0.5$ arc sec or $\lesssim 0.1$ pc) of

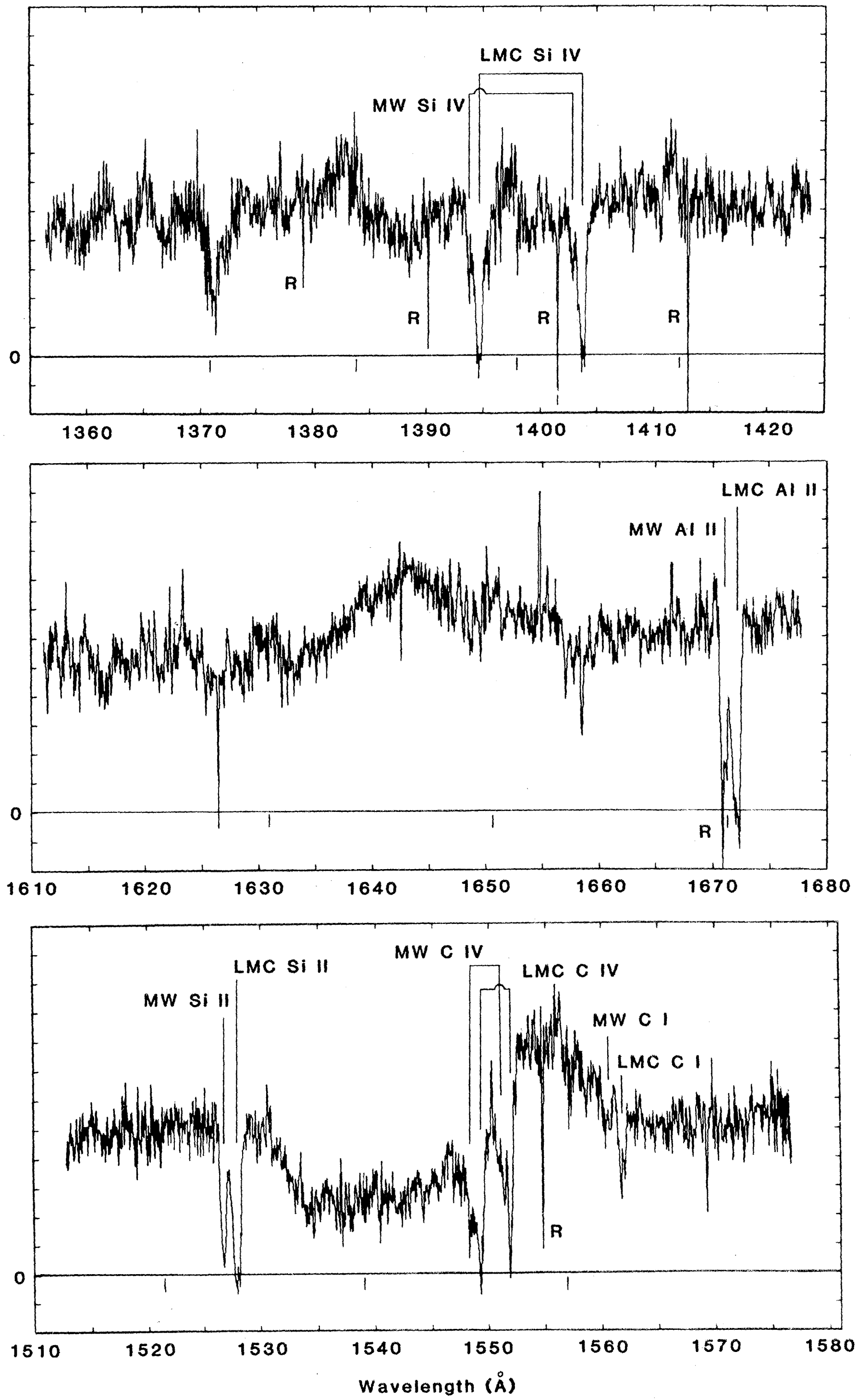

Fig. 2. High-dispersion, large-aperture spectra of R136 from image SWP 8002. The three wavelength regions plotted include the lines of Si IV (1393.8 and 1402.8 Å), He II (1640.4 Å), and C IV (1548.2 and 1550.8 Å). The spectrum in each region was produced by combining the data from three or more echelle orders. Junction points between adjacent echelle orders are marked with vertical lines placed slightly below the zero levels. Milky Way (*MW*) and Large Magellanic Cloud (*LMC*) interstellar absorption features are marked. The wavelengths are plotted as provided by the standard reductions. The wavelength shifts required to allow for the 270 km sec^{-1} radial velocity of the LMC can be inferred from the LMC interstellar lines. The *R* denotes a detector reseau. The high-dispersion, small-aperture spectrum from image SWP 2766 gives results roughly similar to those shown above, although with a much higher noise level.

comparable stars or is dominated by the radiation from a single superluminous object. The continuum spectrum is heavily affected by extinction by foreground dust (6), but the stellar line spectrum provides a great deal of information about the object. The ionization and excitation seen in the lines (C IV, N V, excited N IV and O V, and very weak Si IV) are like those seen in the spectra of stars of the earliest spectral type.

The strong P Cygni He II (1640 Å) and N IV (1718 Å) lines indicate a very large rate of mass loss from R136a by way of a stellar wind. The P Cygni doublet of Si IV (1394 and 1403 Å) is quite strong in O stars cooler than about 50,000 K with strong winds (*10*). Its weakness in R136a shows that such stars do not contribute much of the observed UV radiation. With 50,000 K as a lower bound to the temperature of R136a, the UV and optical data imply a luminosity of about $0.7 \times 10^8\ L_\odot$ (*11*). This peculiar object probably emits more than 3×10^{51} ionizing photons per second (*11*). Thus we conclude from these rough lower limits that R136a is the dominant ionization source of the nebula (*2*).

Can a collection of very hot, "normal" stars (that is, stars with $M \lesssim 150$ to 200 $M_\odot$) produce the spectrum? One of the hottest stars known is the type O3 ((f)) star HD 93250 (*12*), which indeed has weak Si IV and strong C IV, N V, N IV, and O V. Like R136a, it has a wind terminal speed of about 3400 km sec^{-1}. However, it has no P Cygni He II and apparently a relatively low rate of mass loss. Even slightly cooler O stars (such as ζ Pup; type O4f) show strong Si IV and slower winds (~ 2700 km sec^{-1}). The WN3 star HD 5980 (*13*) shows lines similar to those of R136a, but has a wind speed of only 2800 km sec^{-1}. In common with almost all other hot stars, it also has a C IV (1550 Å) line that drops to zero intensity in the blue absorption portion of the P Cygni profile. In R136a, the C IV intensity is flat at about 40 percent of the adjacent continuum for all speeds up to 3200 km sec^{-1}. This precludes much radiation coming from stars with $v_{\mathrm{edge}} \lesssim 2800$ km sec^{-1}.

Thus, if R136a is a cluster of normal stars, the cluster must (i) have a unique luminosity function, with both WN3 and O3 stars present but with the normally numerous cooler stars missing, (ii) have all luminous stars in the cluster possess the largest known wind speed, and (iii) have a filled-in C IV profile, which is most unusual. In addition, if the ionization of the 30 Doradus Nebula is provided by R136a, which is strongly indicated by the fact that the sum of the ionizing fluxes of the other stars in the nebula falls far short of what is needed (*3*), we would need to pack on the order of 30 O3 or WN3 stars within a space of 0.5 arc sec (0.1 pc). Recently obtained speckle interferometry data should refine our understanding of the detailed spatial structure of R136a (*14*). Finally, a cluster of this nature could hardly be variable, while there is a strong suggestion (*3*) that R136a varies in both its V magnitude and its stellar Hα profile. Thus there are fundamental difficulties in interpreting the spectrum on the basis of a collection of normal stars.

Properties of a single object. A single object burning hydrogen appears to have all the observed properties, but would have to have a luminosity and mass far exceeding those of any other known star. It would be as hot or hotter than 52,500 K, the temperature of the O3 ((f)) star HD 93250 (*12*). Such a high temperature is indicated by the stages of ionization in the spectrum. For hot stars, radio observations indicate that the mass loss rate is correlated with the luminosity (*15*), so a very massive wind is expected. By extrapolation from normal stars, we estimate a mass loss $\dot{M}$ of order $10^{-3.5}\ M_\odot$ year^{-1}. For temperatures > 50,000 K, He^+ ionizing photons (energy > 54 eV) are produced in appreciable quantities, so that strong He II emission follows from the absorption of these photons in a thick stellar wind. We expect that any very hot, very luminous star with a thick stellar wind should have Wolf-Rayet characteristics. The strengths of the C IV, N V, and O V lines suggest an upper limit of 70,000 to 75,000 K for the temperature (*16*), above which these elements are ionized further. At temperatures less than 75,000 K, our calculations show that, for $\dot{M} = 10^{-3.5}\ M_\odot\ \mathrm{year}^{-1}$, all of the He^+ ionizing radiation is absorbed in the wind, in agreement with the fact that the nebula shows no He II emission (*17, 18*).

Table 2 shows the parameters of R136a as a single object, assuming that it produces 5×10^{51} ionizations per second, a conservative estimate derived from the radio data (*2*). Column 1 is the assumed effective temperature. Model atmospheres (*19*) provide the flux of hydrogen ionizing photons (column 2). The star's radius R (column 3) follows from this surface flux and the total number of ionizations per second. We obtain $R \approx 90 \pm 40\ R_\odot$ and $L \approx 7.5 \times 10^7\ L_\odot$ for the range of temperatures (50,000 to 75,000 K) considered acceptable on the basis of the spectral features. Such a high luminosity requires that the star be far more massive than any previously

Table 1. Ultraviolet observations.

Star	Image*	Date (year, day)	Resolution	Aperture (arc sec)	Exposure time
R136	SWP 2766†	1978, 269	High	3	7 hours
R136	SWP 6515‡	1979, 258	Low	3	13 minutes
R136	SWP 6515‡	1979, 258	Low	10 × 20	5 minutes
R136	LWR 5584‡	1979, 258	Low	3	10 minutes
R136	LWR 5584‡	1979, 258	Low	10 × 20	3.3 minutes
R136	SWP 7989	1980, 50	High	3	7 hours
R136	SWP 8002	1980, 52	High	10 × 20	3 hours
HD 193793	SWP 8004§	1980, 52	High	10 × 20	70 minutes

*SWP is the short-wavelength prime camera; LWR is the long-wavelength redundant camera. †This spectrum was obtained by de Boer *et al.* (*9*). ‡These spectra were obtained by Koornneef and Mathis (*6*). §Used as a comparison point source to evaluate the spatial extent of R136 image SWP 8002.

Table 2. Properties of stars producing 5×10^{51} ionizing photons per second.

Effective temperature (K)	Flux of ionizing photons* (cm^{-2} sec^{-1})	Stellar radius ($R_\odot$)	Stellar luminosity† ($L_\odot$)	Bolometric magnitude	Unreddened visual magnitude at 55 kpc	Eddington lower mass limit ($M_\odot$)	Estimated stellar mass‡ ($M_\odot$)
40,000	1.40×10^{24}	242	1.33×10^8	−15.69	6.81	3630	4490
45,000	3.17×10^{24}	161	9.40×10^7	−15.31	7.56	2570	3140
50,000	5.64×10^{24}	121	8.06×10^7	−15.15	8.07	2200	2630
55,000	9.56×10^{24}	93	6.96×10^7	−14.99	8.58	1900	2230
60,000	1.33×10^{25}	79	7.08×10^7	−15.01	8.82	1930	2210
75,000	3.44×10^{25}	49	6.69×10^7	−14.94	9.62	1830	2000
90,000	7.03×10^{25}	34	6.78×10^7	−14.96	10.15	1850	1970

*Number flux of H ionizing photons at the stellar surface as derived by Hummer and Mihalas (*19*). †Stellar interior models constructed with $n = 3$ polytrope theory and an assumed hydrogen abundance of $X_H = 0.75$ yield the luminosities listed here at an effective temperature of ≈ 63,000 K. ‡Estimated by assuming the empirical relation for terminal velocity versus escape speed valid for O stars (Eq. 1).

known. A firm lower limit on the mass is the Eddington limit (column 7), at which the inward acceleration of gravity is balanced by the outward radiation pressure gradient acting on electron-scattering opacity. This mass limit is $M_{Ed} \geq \sigma_e L(4\pi cG)^{-1}$, where σ_e is the electron-scattering mass absorption coefficient of $0.20(1 + X)$ cm^2 g^{-1} (X = fraction of H by mass), L is the luminosity, c is the speed of light, and g is the gravitational constant. For $L = 7.5 \times 10^7 L_\odot$, we find $M_{Ed} \geq 2000 M_\odot$. We can make a better estimate of the stellar mass. The empirical relation for O stars (*20*) between the wind speed, v_∞, and the effective escape speed is

$$v_\infty = 3\, v_{escape} = 3[2G(M - M_{Ed})/R]^{1/2} \quad (1)$$

The stellar mass derived from this relation is given in the last column of Table 2.

If R136a produces 10^{52} ionizations per second, as indicated by some radio observations (*2*), its luminosity and estimated mass would approximately double, to $1.4 \times 10^8 L_\odot$ and $4400 M_\odot$, respectively.

The mass loss rate from R136a could, in principle, be derived from the UV line profiles, but this requires knowledge of the fractional abundance of the ions producing the lines. Rough estimates based on the C IV line yield $\dot{M} > 4 \times 10^{-4} M_\odot$ year^{-1}. A minimum mass loss rate can also be derived by requiring that the He^{2+} ionization zone be confined to the wind, to explain the absence of the He II 4686 Å recombination line in the nebula. This gives $\dot{M} \gtrsim 1 \times 10^{-4}$ for an effective temperature of 50,000 K and $\dot{M} \gtrsim 1 \times 10^{-3}$ for 90,000 K. Perhaps the most reliable method for estimating the magnitude of the mass loss rate is by extrapolation from ordinary stars with similar spectral characteristics. The mass loss rates derived for early Of stars are of order $L/v_\infty c$ ($\approx 4 \times 10^{-4} M_\odot$ year^{-1} for R136a), and the mass loss rates for Wolf-Rayet stars are $\approx 8\, L/v_\infty c$ ($\simeq 3.2 \times 10^{-3} M_\odot$ year^{-1} for R136a). We choose to use $\dot{M} = 10^{-3.5 \pm 1} M_\odot$ year^{-1} as a reasonable estimate of the mass loss rate of R136a.

The peculiar C IV line is readily explained by the single-star hypothesis. Both the large- and small-aperture spectra show the line with the large terminal velocity of $\approx$ 3500 km sec^{-1}. The residual intensity in the absorption component seen in the small-aperture spectrum is somewhat smaller, as expected if there is more contamination of the large-aperture spectrum by neighboring stars. The remaining residual intensity can be explained with at least two mechanisms that are not applicable to the cluster model. First, for mass loss rates $\gtrsim 10^{-3}$ $M_\odot$ year^{-1}, the electron-scattering optical depth of the wind is of order unity. Stellar light passing through the noncoherent electron-scattering atmosphere should give rise to the washed-out appearance of the optical spectra of R136 (*8*) and to the filling-in of the C IV absorption trough (*21*). Second, a homogeneous supermassive star should be hotter than ordinary stars, as discussed below, and the abundance of C^{3+} should be lower. The fractional abundance of C^{3+} decreases from 10^{-2} to 10^{-5} for stellar effective temperatures increasing from 50,000 to 70,000 K. Thus at the higher temperatures the carbon could be too highly ionized to produce optically thick C IV. Reliable measurements of the depth of the P Cygni N V (1238 and 1242 Å) line may discriminate between these two suggestions.

The interior of a supermassive star is well described by an $n = 3$ polytrope. All properties of the model are fixed by specifying M and R. We take an effective temperature (and R) from Table 2 and use the polytropic relations (*22*) to determine the central temperature. We then make an independent determination of L by integrating the standard luminosity equation outward, assuming CNO hydrogen burning. The luminosity increases very rapidly as the assumed effective temperature is increased. It is as large as that required to account for the nebular ionization for $\simeq$ 63,000 K. This is just in the range allowed by the spectral lines, and provides an independent check on the plausibility of the supermassive star hypothesis. The star should be very nearly homogeneous and remain so during its evolution because of convective mixing in the interior and rapid removal of the atmosphere by mass loss. This should lead to a depletion of the atmospheric abundance of carbon and oxygen relative to nitrogen.

There are well-known problems with the stability of a supermassive star against pulsations (*23*). We may see the effects of instability in the massive stellar wind. Some variations in brightness might be expected and should be searched for. Similarly, the formation of supermassive stars is not easily understood (*24*), because the large luminosity of an accretion shock at the top of the collapsing prestellar cloud will stop the infall of the grains, which are in turn coupled to the gas. The LMC has significantly less dust per gram of gas than our Galaxy (*9*). Also, a protostar of large mass should have a low density, and the grains may be driven through the gas fast enough to be destroyed by sputtering. Grain sputtering apparently occurs in the winds of red supergiants (*25*).

Follow-up studies of R136a are certainly warranted. The object will be monitored with IUE to search for line profile and continuum variability. Coordinated ground-based programs would be highly desirable. X-ray observations obtained by the Einstein observatory may provide further constraints on the nature of R136 (*26*). Other galaxies might contain similar objects (*27*). Ultimately, the Space Telescope will be able to obtain important observations of R136a and related objects with a combination of high spatial and high spectral resolution.

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by high temperature rather than simply a low Si abundance in the LMC.
11. Estimation of L and n_c, the luminosity and number of ionizing photons, is complicated by two major uncertainties: contamination of the spectrum of R136a by other stars and the large and peculiar extinction by dust. If all the visual light of R136 arises from R136a, with T = 50,000 K, apparent visual magnitude V = 10 (3), distance d = 55 kpc, and visual extinction A_V = 1.8 magnitudes, then $L \approx 7 \times 10^7\ L_\odot$ and $n_c \approx 4 \times 10^{51}$ sec^{-1}. Photographs (3) suggest that R136a is responsible for most but not all of the visual radiation from R136. Hence $L \approx 5 \times 10^7\ L_\odot$ and $n_c \approx 3 \times 10^{51}$ sec^{-1} are not unreasonable estimates. If the temperature of R136a is 60,000 K, L and n_c would approximately double under the same assumptions. It is difficult to estimate A_V. We used various nebular Balmer line/radio continuum ratios to estimate the extinctions at Hα and Hβ [for example, see (2)]. By interpolation, we obtained A_V between 1.6 and 2.1 mag. We consider it reasonable to assign the same extinction to R136a. While some of the nebular dust may be behind the star, thus not contributing to the stellar extinction, the nebular Balmer lines are affected primarily by the absorption of the dust (as opposed to scattering). For the Balmer lines, the absorption of Galactic dust is less than half the extinction [B. D. Savage and J. S. Mathis, *Annu. Rev. Astron. Astrophys.* **17**, 73 (1979), sect. 3.1], so our assumed extinction is probably conservative. The colors of R136 suggest a color excess of $E(B - V)$ = 0.38 [F. P. Israel and J. Koornneef, *Astrophys. J.* **230**, 390 (1979)]. Using $A_V/E(B - V)$ = 4.65 derived from the Balmer lines, we find A_V = 1.8. However, the dust near R136 is likely to be peculiar; for instance, the UV extinction of R136 (6) is somewhat different from that of the general LMC. The extinction for the UV is even more difficult to estimate than for the visual. We suggest that it is about A(1400 Å) = 4 ± 1 mag, based on A(3000 Å) − A_V = 1.5 as derived from the Galactic and LMC extinction laws, A_V = 1.8 mag, and A(1400 Å) − A(3000 Å) = 1.3 mag from IUE observations (6). If we assume that A(1400 Å) = 4 mag and that R136a is responsible for 70 percent of the large-aperture 1400 Å flux, we find $L \approx 5 \times 10^7\ L_\odot$ and $n_c \approx 3 \times 10^{51}$ sec^{-1} for 50,000 K, and values ~ 1.5 times larger for 60,000 K.
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13. High-dispersion IUE observations of HD 5980 (OB?+WN3) in the Small Magellanic Cloud obtained by one of us (B.D.S.) reveal P Cygni lines of N V, C IV, He II, and N IV. The stellar Si IV is very weak, as in R136a. A photospheric O V 1371 Å feature is present. The absorption part of the C IV profile saturates. The edge of this line implies a terminal speed of 2800 km sec^{-1}.
14. We recently learned that G. Weigelt (private communication) has speckle interferometry measurements of R136a with the ESO 3.6-m telescope at La Silla, Chile. He has not completed the reduction of his data, but his preliminary results indicate that R136a consists of two objects with a magnitude difference of 2 in a complicated background. This seems in accord with our conclusion that a single object dominates the UV spectrum. We thank Dr. Weigelt for permission to cite his results before publication.
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26. We expect on the basis of x-ray observations of O and B supergiants (J. P. Cassinelli *et al.*, *Astrophys J.*, in press) that the x-ray luminosity of the star might be of order $10^{-7.5}\ L_{bol}$ (10^{34} erg sec^{-1}), where L_{bol} is the bolometric luminosity, and some of this would be attenuated by intervening interstellar matter [hydrogen column density = 7×10^{21} (9)]. A dense cluster of O stars, on the other hand, might be a strong x-ray source because of the collision of the various stellar winds [B. A. Cooke, A. C. Fabian, J. E. Pringle, *Nature (London)* **273**, 645 (1978)]. A shock at the interface of the observed outflow and the surrounding interstellar medium might also be a source of hard x-rays [J. Castor, R. McCray, R. Weaver, *Astrophys. J. Lett.* **200**, L107 (1975)].
27. IUE low-dispersion spectra of supergiant H II regions have been published: NGC 604 in M33 and NGC 5471 in M101 by M. Rosa [*Astron. Astrophys.* **85**, L21 (1980)] and regions in NGC 2366 and K 2574 by P. M. Gondhalekhar, D. H. Morgan, K. Nandy, and R. Wilson [in *Second European IUE Conference* (ESA-Sp-157, European Space Agency, Paris, 1980), p. 131]. The spectrum of NGC 604 appears to be compatible with that of a cluster of normal O stars (strong Si IV); NGC 5471 has a spectrum resembling that of an exceedingly hot object.
28. B.D.S. is a guest observer with the IUE satellite, which is sponsored and operated by the National Aeronautics and Space Administration, the Science Research Council of the United Kingdom, and the European Space Agency. We thank the entire IUE staff at Goddard Space Flight Center for their assistance in acquiring and processing the IUE data included in this report. We thank M. R. Meade for her assistance with the data processing. B.D.S. acknowledges support from NASA grants NSG 5241 and 5363, J.P.C. from NSF grant AST-7912141, and J.S.M. from NSF grant AST-7906829. Useful comments on the manuscript were provided by a number of colleagues, especially L. Hartmann.

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Solar Flare Acceleration of Solar Wind: Influence of Active Region Magnetic Field

Abstract. *The direction of the photospheric magnetic field at the site of a solar flare is a good predictor of whether the flare will accelerate solar wind plasma. If the field has a southward component, high-speed solar wind plasma is usually observed near the earth about 4 days later. If the field has a northward component, such high-speed solar wind is almost never observed. Southward-field flares may then be expected to have much larger terrestrial effects than northward flares.*

Solar flares that occur in active regions where the photospheric magnetic field has a southward component tend to be associated with enhanced solar wind velocity observed near the earth 4 days later. This was observed in both the northern and southern solar hemispheres during portions of the last two 11-year sunspot cycles. During most of the time interval investigated, the solar field polarity was outward in the north and inward in the south.

For this report we used all the flares in the interval 24 August 1978 through 9 November 1979 with importance 2 or greater, as reported by the group observations in Solar-Geophysical Data (1). Flares whose disk longitude exceeded 70° were not used. The start of the interval was determined by the beginning of observations by the Los Alamos solar wind experiment on the spacecraft International Sun-Earth Explorer 3 (ISEE-3), and the end of the interval was selected

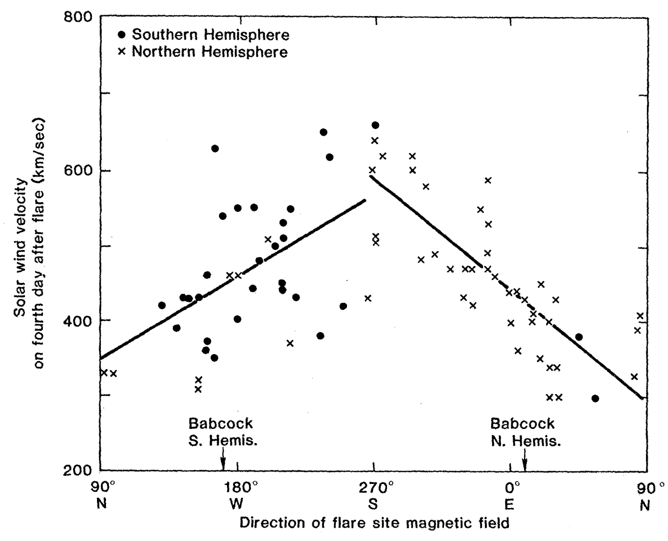

Fig. 1. Solar wind velocity observed near the earth on the fourth day after a flare as a function of the direction of the flare-site photospheric magnetic field.

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