PANEL DISCUSSION ON R136

The second panel of this symposium discussed the nature of R136 in 30 Doradus. The panel consisted of Y.-H. Chu, J.V. Feitzinger, B.D. Savage, W. Seggewiss, N.R. Walborn and T. Schmidt-Kaler (chairman).
The panel members presented their views of R136, followed by replies, comments, and some discussion, while a few remarks were made from the audience. We reproduce here the opening statements of the panelists. All references have been collected at the end.

Th. Schmidt-Kaler
Ruhr University, Bochum

1. Introduction. Conventional theory of stellar structure places an upper limit for stellar masses at 60-120$M_\odot$. At the 1979 IAU Assembly in Montreal I announced the discovery of R136a as the first supermassive star (Schmidt-Kaler 1980), its mass exceeding 500 $M_\odot$. Cassinelli et al. (1980,1981) confirmed the discovery at the 1981 AAS Spring meeting by means of IUE observations and gave a model of the star with mass of the order of 2500 $M_\odot$. Subsequently R136a became the object of many investigations. Furthermore, quite a few examples of supergiant HII regions in other galaxies have been identified which apparently must be excited by similar stars (Conti and Massey 1981, Osterbrock and Cohen 1982, D'Odorico and Rosa 1982, Massey end Hutchings 1983, Grothus and Schmidt-Kaler 1983). We have new results from optical and ultraviolet spectra, and from surface photometry of the surrounding nebula confirming the nature of R136a and showing that R136a is responsable for energizing and structuring the whole supergiant HII region 30 Doradus.

2. Basic observational parameters. The various observers seem to reach agreement on important parameters:
a) The visual magnitude of R136a_1. The best estimate of the magnitude difference between a_1 and a_2 seems to be 1.2 mag. This yields

Schmidt-Kaler,Feitz.(1981)	(2"2)	$V(a_1+a_2)$= 10.77	$V(a_1)$= 11.08
Chu (1984)	(3")	-	11.22
Schlosser (1984)	(1"3)	10.62	10.93
			11.08±0.08

b) The reddening E(B-V)

Schmidt-Kaler,Feitzinger (1981)	0.46	various methods
Walborn (1982)	0.44	nebula (central object)
Melnick (1983)	0.46	MK and B-V of O-stars
Fitzpatrick,Savage (1983)	0.34	UV spectra in LMC.

The difference may be due to the fact that the last authors intercompare only LMC stars. Foreground dust common to all stars would not be noticed.

S. van den Bergh and K. S. de Boer (eds.), Structure and Evolution of the Magellanic Clouds, 263–270.

c) The ratio $R = A_V/E_{B-V}$. For the galactic foreground and LMC general dust R = 3.25, for 30 Dor nebular dust it is

Le Marne (1968)	7
Melnick (1978)	5.0
Israel,Koornneef (1979)	6.5
McGregor,Hyland (1981)	5.0
Clayton et al. (1983)	4.4
Savage et al. (1983)	3.7, 5.0
	5.5

d) The extinction is therefore at least $A_V=1^m.5$, but more probably $2^m.0$. It depends on the relative contributions of galactic, and LMC foreground, and 30 Dor dust.

e) The optically determined luminosity then is $M_{bol}=-15.0$ or $L=7\ 10^7\ L_\odot$ (using B.C.=−5.5 for T=62000 K). The UV liminosity according to Savage et al. (1983) is $6\ 10^7\ L_\odot$.

f) The spectrum. Recent optical spectral classifications are

Ebbets,Conti (1982)	abs (O)+WN4.5
Vreux et al. (1982)	O3f
Moffat,Seggewiss (1983)	WN6+O3-4
Schmidt-Kaler (1983)	O2f (+WN4.5)

The photographic spectra of Moffat and Seggewiss are contaminated by stray light from the central object in conjunction with atmospheric dispersion. Our 1.5m-IDS sky-corrected spectrum is in excellent agreement with Melnick's 1983 4m digital spectrum, while in Moffat's spectra many important features are missing or unclear. R136 shows no SiIV and HeI in absorption, HeII λ4542 is in wide absorption (±1000 km/s) plus central emission, H_β like H_α with wide emission wings (±3000 km/s).

3. The physical properties of R136a are listed in the following table.

	Multiple System or Cluster Core	Single Star R136a1		
		Schmidt-Kaler and Feitzinger 1981 Bochum	Panagia et al. 1983 Bologna	Savage et al. 1983 Wisconsin
Luminosity	$10^7\ L_\odot$	$7\ 10^7\ L_\odot$	$6\ 10^7\ L_\odot$	$6\ 10^7\ L_\odot$
Temperature	---	62000 K	52000 K	75000 K
Radius	---	65 $R_\odot$	84 $R_\odot$	50 $R_\odot$
Mass	several stars with $M \leq 220$ to 280 $M_\odot$	2500 $M_\odot$	>2000 $M_\odot$	≈2100 $M_\odot$ (>800 $M_\odot$)
Mass-loss	----	$4\ 10^{-4}\ M_\odot/a$	$5.2\ 10^{-4}\ M_\odot/a$	$5\ 10^{-4}\ M_\odot/a$

R136a shows apparently normal chemical abundances from its spectrum (Feitzinger et al. 1983).

4. Formation of Supergiant HII-regions. From our survey and Hodge's (1983) size distribution function of HII regions of galaxies the supergiant HII regions represent a seperate class of objects. The same appears to be true for the mass function of the exciting stars. The supermassive stars are probably formed by a new seperate mechanism, when four (or more) adjacent, strongly expanding HII regions powered by (nearly simultaneously formed) massive O stars squeeze a molecular cloud in between then into collapse. In this way stars of extremely high masses may be formed.

N.R. Walborn
Goddard Space Flight Center

I wish to emphasize the following three points, which are discussed at greater length in my review (Walborn 1984).
1). The potential contribution to the ionization of the 30 Doradus Nebula by the cluster stars other than R136 has been substantially underestimated in some recent discussions. More than half of the ionizing luminosity probably is provided by stars other than R136.
2). Detailed comparisons between R136 and HD97950 (NGC3603) show that they are virtually identical multiple systems (see Seggewiss and Moffat 1984, and Rosa, Melnick and Grosbol 1984).
3). The previous conflict between two speckle interferometry observations of R136a, one showing an unresolved and the other a multiple object, has been definitely decided in favor of the latter by independent visual micrometer and photographic observations (see also Chu 1983).

The following spectroscopic points are also relevant. The wind terminal velocity of 3600 km/s seen in R136a is, in fact, typical for O3-O5 stars; indeed the terminal velocity of the O3 comparison star R122 is 4000 to 5000 km/s. The recent discovery of "intermediate" O3/WN objects such as Sk-67°22 and Melnick 30, 35N and 39 (Melnick 1983), is also important in the interpretation of R136; these objects may provide an O3 UV flux and relatively weak WR bands simultaneously. The Melnick stars are adjacent to R136, with $M_V = -6.8$ for No 39. Melnick 42 appears to be an O3If* object with $M_V = -7.5$.

B.D. Savage
Washburn Observatory

This discussion will concentrate on the UV measurements of R136a contained in Cassinelli, Mathis, and Savage (1981), Savage et al. (1983), and Fitzpatrick and Savage (1984). The second of these papers represents a reasonably complete analysis of all the stellar UV data relating to R136a that we have obtained with the IUE satellite. R136a is a difficult object to study because it lies in a crowded field. Observations in different spectral regions experience differing amounts of contamination from stars near R136a depending on aperture size and shape, and on the effects of atmospheric seeing. In Savage et al. (1983) this contamination problem was carefully addressed and it was found highly desirable to restrict the analysis to the IUE small (3") aperture data. However, the contamination problem doesn't go away with the use of the small aperture. The 3" diameter aperture accepts radiation from components R136a1, R136a2, and the extended emission which is approximately centered on component a1 (see Chu 1984).

The de-reddened small aperture UV spectrum of R136a is illustrated in Figure 2 of Savage and Fitzpatrick (1984). To produce that spectrum the IUE small aperture fluxes were increased by a factor of 2 to correct for the small aperture light losses expected for a point source. A similar correction factor is required to correct for the aperture light loss experienced by the extended component detected by Chu.

The line spectrum of R136a resembles to that of O3 stars. Strong P Cygni lines of N V, N IV, O V, and C IV are present while the Si IV P Cygni feature is absent. In addition the He II 1640Å line is P Cygni in appearance with a strong broad emission component. He II emission this strong is nct normally seen in O3 spectra. If the spectrum of R136a is produced by a group of normal stars the requirement is $\simeq$ 13 R122's to produce the O3 characteristics and $\simeq$ 15 normal luminosity early WN stars to produce the He II emission. R122 (O3 III(f*)) is the most luminous normal star in the LMC with $L \simeq 3\ 10^6 L_\odot$ and a mass estimated to be about 200 $M_\odot$. If less luminous O3 stars, such as Sk67-22, are producing the spectrum of R136a, then the number requirement for O3 stars increases to about 40. The C IV line in R136a has a blue edge which rises rapidly between 3000 and 3600 km/s. If a group of stars is producing the R136a spectrum, the dominant UV emitters in that group must have C IV P Cygni lines with edge velocities between 3000 and 3600 km/s. In the LMC, only the O3 stars have wind velocities that large. It was primarily on the basis of the C IV line profile that Cassinelli, Mathis, and Savage (1981) concluded that the UV light from R136a is more likely dominated by the emission from a single object. On the basis of Chu's visible imagery, it now appears that R136a may be that object. With $M_V \simeq -8.5$ and an O3 spectrum implying $T \gtrsim 50{,}000$ K, R136a1 would have a luminosity of $\gtrsim 1.5\ 10^7 L_\odot$ and a mass of $\gtrsim 600\ M_\odot$. The speckle measurements of Weigelt (private communication) imply that component a1 has a diameter of less than 0.02 pc. We can't rule out the possibility that component a1 is a multiple system of perhaps ten of the most luminous O3 stars. In this case the He II emission might be provided by component a2 if it is a superluminous Wolf-Rayet star. The formation of such a multiple system of O3 stars seems as implausible as the formation of a single supermassive object.

W. Seggewiss
Observatorium Hoher List

HD38268 = R136a is a most remarkable diffuse object (V= 10.0 mag in a diaphragm of 7" diameter) in the centre of the young populous cluster NGC2070 in the 30 Dor nebula. Already in 1982 we found (Moffat and Seggewiss 1983) that:
a) the spectrum changes across the face of R136a; the WN spectrum peaks in the centre whereas the early O-type spectrum is approximately constant over R136a (spectral type of the centre is WN6 + O3-4);
b) the visual light distribution is definitely not that of a single star.

In early 1983 we "rediscovered" the visual observations by van den Bos (Innes 1927) which resolve R136a into four components A, B, C and D. This is confirmed by photographic observations by Chu (1984) who found in addition two more faint components. Weigelt (1981) announced that speckle interferometry has revealed more stars in the main component

R136A (=R136a1). Thus, the apparent visual magnitude of R136A can not be much brighter than V = 12 mag. This compares to the magnitude of the brightest WN6 star in the surrounding cluster NGC20270: V = 11.9 mag. In contrast, early O-type stars (see above (a); V = 14 for O3V stars) contribute to the main unresolved stellar background light and to the UV flux.

The recognition, however, of the huge population of early-type stars in the central region of the 30 Dor nebula by Walborn (1984) and the construction of the colour-magnitude diagram of NGC2070 by Melnick (1983; 55 stars brighter than M_V= -5.2 mag, the absolute magnitude of an O4 ZAMS star) demonstrate that R136 is not the main contributor to the ionizing Lyman continuum flux of the nebula.

Note: New determinations revise downward not only the interstellar absorption A_V to 1.2 (Savage et al. 1983; Melnick 1983) but also the effective temperature for both the ionizing source of the nebula to T(eff) = 38000 K (Lequeux et al. 1981) and the O3-type stars to T(eff) = 45000 K (Simon et al. 1983).

The comparison between the galactic cluster NGC3603 and R136a was made by Walborn (1973, 1984). We like to point out the drastic difference between the open clusters of the Galaxy and young populous clusters of the LMC. The main body of the cluster NGC3603 can be placed inside R136a, the core of the populous cluster NGC2070, i.e. R136a, is not such an unusually compact object. Calculations of the relaxation time of R136a (as a cluster core), using a realistic initial mass function, lead to values of the order of 10^7 years. The central stellar density is below densities observed in globular clusters.

While in the visual spectral range the "problem" R136a seems to be solved, the enormous UV flux, as derived by Savage et al. (1983) and Savage and Fitzpatrick (1984), deserves further attention. They conclude that, within a circle of 3" (the IUE small aperture), R136a is brighter in the UV than 13 O3f-type stars like R122.

J.V.Feitzinger
Ruhr University, Bochum

New optical and UV observations favour the interpretation of R136a1 as a supermassive object.

1. Surface Photometry: R136a1 lies in the centre of the extremely young cluster NGC2070, with the most recent star forming event having taken place less than 10^6 years ago. The age of the giant star population from IR measurements confirms this (McGregor and Hyland 1981). Fitting of King's luminosity profile of isothermal spherical clusters and their extrapolation to the innermost core (Moffat and Seggewiss 1983) is, in the present case, inadequate. The extrapolation used our seeing-limited (FWHM $\simeq$ 1".2) surface photometry (Feitzinger et al. 1980). To see if the

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innermost luminosity structure (< 1") has a spike or not requires resolution better than ≃ 0".3. The situation is similar to that in the core of M82, where conventional seeing-limited data do not reveal the central luminosity spike; a simple King profile fit being clearly inadequate (Young et al. 1978). Chu (1984, Chu and Wolfire 1983) with the best resolved photographs (≃ 0".2) of R136a showed that the "light distribution in R136a is strongly peaked to the center and disagrees with Moffat and Seggewiss (1983) interpretation". Speckle observations (Weigelt 1981, Meaburn et al. 1982) are discordant regarding the faint background, but concordant in revealing the existence of a small bright component, with an upper limit of the diameter of 0".08 (or even 0".02) = 0.02 pc. This is also found by Chu (1984). For the brightness of the central object R136a1 we obtain V = 11.08 mag, carefully taking into account contributions from the companion R136a2 (0".5 apart, ca. 1.5 mag fainter) and from the nebula.

2. The Spectrum: The IUE spectrum (Feitzinger et al. 1983) and the optical spectrum, together with UBV photometry (Feitzinger and Isserstedt 1983) allows temperature determinations from emission lines and by continuum fitting. From the emission lines we deduce 60000 K $\leq$ T $\leq$ 90000 K. By continuum fitting we derive for a blackbody 55000 K, for a model approximation 63000 K. This high temperature means that at least 50 % - 70 % of the 30 Dor nebula is ionized by the central object. Walburn's stellar population (this Symposium) can account for at most 68 % of the excitation (assuming the earliest spectral classifications), and at least 8 % (assuming the latest types), with a median of 20 %.

3. The environment of R136a: The stellar wind power of 4 10^{39} erg/s of R136a is sufficient to energize the major part of the 30 Dor shells and to structure the whole nebula. The expansion velocity of the inner shell is 25 km/s. The deduced age is 4 10^5 yrs. The central object cannot be much older than 1 10^6 yrs.

The Bochum group therefore favours the interpretation of R136a1 as a single object, equivalent to approximately 30 03 stars in an area of less than 0.02 pc. At the moment the possibility of three or four stars of 300 $M_\odot$ - 400 $M_\odot$ each (or two of 700 $M_\odot$ and 1600 $M_\odot$) can not be ruled out completely. This might be the case if the visually brightest component should not be responsible for the UV flux. In any case the core region would be extraordinary in luminosity and density (a factor 100 greater than the globular cluster centers). Whatever the nature of R136a is, this object plays the key role in understanding other supergiant HII-regions.

Y.-H. Chu
Washburn Observatory

Of course, R136a is the core of a dense cluster. But, does it contain a supermassive star? And, how supermassive is it? The assumption of a dominating single source within a 3" aperture would simply pre-

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determine the nature of this source. Comparison between NGC2070 and NGC3603 or other systems cannot place any real constraints on the nature of R136a, since similar appearance is a necessary but not sufficient condition for identical nature. Before high spatial resolution (better than 0".1) UV photometry and spectra of the stars in R136a are available, I don't think anybody can convincingly answer the questions.

R136a is definitely worth further investigations.

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30 Doradus

Doradus, your stars are shining bright above
Doradus, your central object is my love
I press you, caress you,
and bless the day you taught me to care
To always remember
the supermassive cluster you bear
Doradus, when day is done you'll hear my call
Doradus, I'd like to solve your puzzles all
I dread the dawn when I awake to find you gone
Doradus, I need you, my own

Post-Panel Statement, Monastery Bebenhausen, between 7 and 10 p.m.

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