THE POPULATION OF MASSIVE STARS IN R136 FROM HST/FOC UV OBSERVATIONS *

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Abstract. New ultraviolet ($\lambda \simeq 1300$ A, $\lambda \simeq 3400$ A), *HST FOC* observations have been used to derive the UV color–magnitude diagram (CMD) of R136, with the main scientific goal of studying the upper end of the stellar mass function at ultraviolet wavelengths where the color degeneracy encountered in visual CMDs is less severe. The CMD has been compared to a set of theoretical isochrones, which have been computed using the latest generation of evolutionary models and model atmospheres for early type stars. Wolf-Rayet stars are included. Comparison of the *theoretical* and *observed* CMD suggests that there are no stars brighter than $M_{130} \simeq -11$. We use the observed main sequence turn-off and the known spectroscopic properties of the stellar population to derive constraints on the most probable age of R136. The presence of WNL stars and the lack of red supergiants suggests a most likely age of 3 $\pm$ 1 Myr. A theoretical isochrone of 3 $\pm$ 1 Myr is consistent with the observed stellar content of R136 if the most massive stars have initial masses around $\simeq 50\ M_{\odot}$.

Key words: massive stars - IMF - clusters

1. Introduction

R136 is the brightest cluster in the giant HII region 30 Doradus in the Large Magellanic Cloud. R136a is its bright core, which remained unresolved for many years. The interpretation of the nature and the stellar content of R136a has been controversial. Once it was believed to be a single superluminous supermassive star $\simeq 2100\ M_{\odot}$ (Feitzinger et al. 1980; Cassinelli et al. 1981; Savage et al. 1983) or a small group of supermassive stars formed by ordinary stellar collapse in a region containing peculiar dust or by the coalescence of stars in a dense region. Speckle interferometry observations (Weigelt & Baier 1985; Neri & Grewing 1988) later confirmed that R136a is a cluster. However, only several years later the Hubble Space Telescope (*HST*) unambiguously resolved and measured the flux of the brightest components, both with the Faint Object Camera (*FOC*) (Weigelt et al. 1991) and with the Wide Field Planetary Camera (Campbell et al. 1992, Malumuth et al. 1992, Heap et al. 1993).

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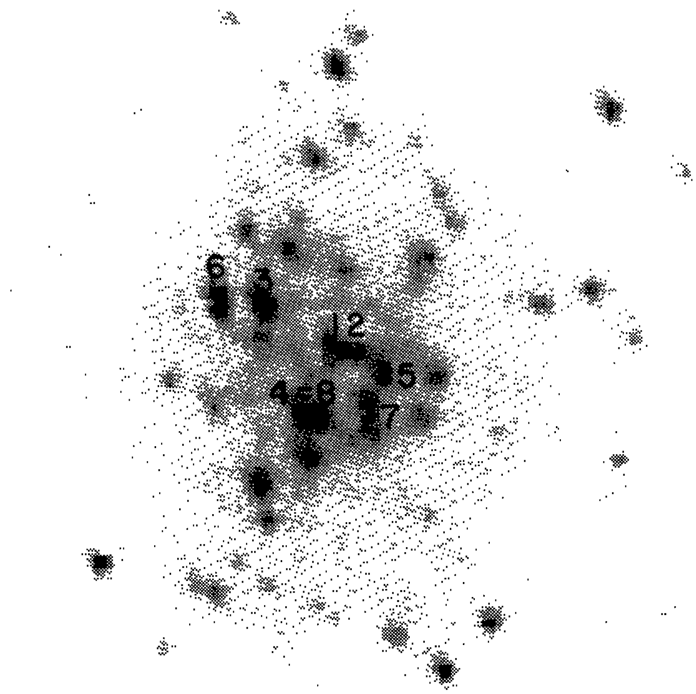

Fig. 1. Enlargement of the 4.44" × 4.44" region around the R136 cluster center, taken with the FOC F130M filter. North is up and East to the left and Weigelt's components a_1 - a_8 have been labelled.

R136a itself is resolved into at least 12 components (Campbell et al. 1992), three of which are found to be Wolf-Rayet (W-R) stars from the emission in the HeII λ4686 line. The brightest stars within R136 are found to have luminosities and colors of *normal* massive stars still on the main sequence or already evolved into the supergiant or Wolf-Rayet phases, in overall agreement with the claim of Moffat et al. (1985) who had already suspected that R136 *does not* contain extraordinarily bright stars.

2. Observations

Observations of R136 were performed on 22 August 1990, 4 January 1991, and 2 February 1991 with the *HST-FOC* in its F/96 mode. The 22 August 1990 observation was obtained with the filter combination F346M + F8ND, and an exposure time of 597 seconds. A few months later, 4 additional images of the same region were taken with the filter F130M and an exposure time of 900s each. The two filters used, their characteristics, and the instrument set-up are described in detail in De Marchi et al. (1993). The F130M images, largely overlapping, have been used to create a single, high signal-to-noise image of the central area of the cluster. The final summed F130M image is shown in Figure 1, with a plate scale of 0.022" pix^{-1}. The F346M image has been aligned to the F130M sum. The resulting overlap area of the two filters is $\simeq$ 113 $arcsecs^2$, but the two images differ considerably in quality: using the brightest stars we can estimate that the S/N ratio in the F130M summed image is $\simeq$ 28 while it is $\simeq$ 7 in the F346M frame.

3. The Color Magnitude Diagram

We located 221 stars in the F130M summed image, which were also found in the F346M frame with, at least, a SNR of $\simeq$ 2.5 in their peak. The photometric reduction followed the "core aperture photometry" technique, and was calibrated through the comparison with standard stars taken with the same filters. While internal photometric errors are better than 0.10 mag at worst, the quite large uncertainty in the UV calibration of the FOC causes the overall accuracy of our fluxes to be about 20%. Magnitudes measured this way are used to derive the CMD shown in Figure 2. To make easier the comparison with theoretical isochrones, absolute dereddened magnitudes were plotted. We assumed a distance modulus of 18.55 $\pm$ 0.13 (Panagia et al. 1991) and estimated the total intervening absorption as due to three different components: the Milky Way and the LMC (Fitzpatrick 1985), and the 30 Doradus nebular dust (Fitzpatrick & Savage 1984). Our best estimate for the intervening absorption is E(B-V) = 0.41, A_{130} = 4.31 mag, and A_{346} = 2.21 mag. The eight components (actually only seven, because a4 = a8) of R136a originally resolved by Weigelt & Baier (1985) are labelled by number in our CMD. Interestingly, they are the brightest stars in the cluster and also among the reddest, and are clearly concentrated within the innermost 1" radius.

4. The Isochrones

Theoretical isochrones have been derived using evolutionary models by Maeder (1990) and Maeder & Maynet (1988) to cover masses up to 120 $M_\odot$. LTE model atmospheres with line blanketing (Kurucz 1992) are adopted for stars which are not in their W-R phase. Emergent fluxes of W-R stars are calculated with the theoretical continuum energy distribution of Schmutz et al. (1992, 1993). Model atmospheres have been renormalized to derive the expected fluxes in the FOC bandpasses, and finally converted into HST instrumental magnitudes by using the FOC-specific FOCSIM simulator. We compared the observed CMD to theoretical isochrones to estimate the age and the mass spectrum of the cluster. The presence (already known from the ground) of W-R stars in R136 (Melnick 1985) sets a lower limit for the age of this cluster of at least 2 Myr. Conversely, the presence of WNL stars, along with the detected lack of red supergiants, suggests an age no larger than $\simeq$ 4 Myr. The isochrones we overlay on our CMD in Figure 2 correspond to 3 and 4 Myr, for Z = 0.25 $Z_\odot$. The fit between observed

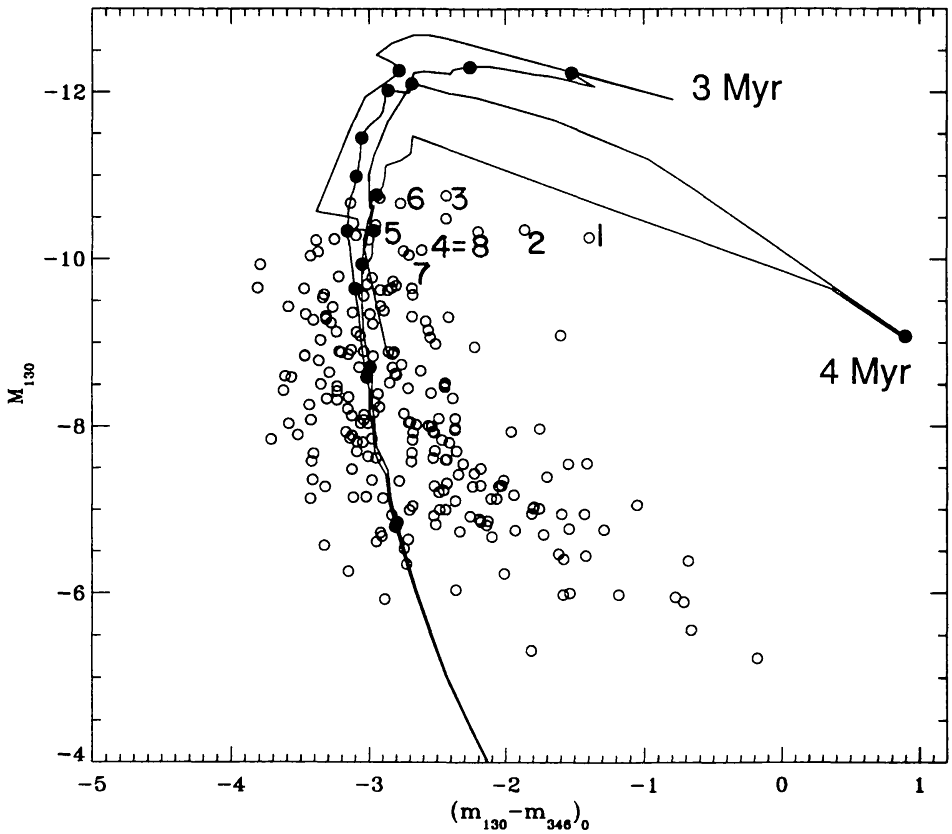

Fig. 2. Isochrones corresponding to 3 and 4 Myrs and $Z = 0.25\ Z_\odot$ are superimposed on our observed CMD. Filled circles along the isochrones represent mass steps starting from 10 $M_\odot$ (at $M_{130} \simeq$ -6.8), with a sampling of 10 $M_\odot$. The dashed line indicates the 4σ detection limit.

and theoretical distribution is clearly better for main sequence stars than fainter than $M_{130} \simeq$ -10 than for brighter stars. In other words, we do not observe the theoretically expected population of very bright and very massive stars which have recently left the main sequence towards the supergiant and W-R.

Among the possible interpretations of this finding, we favor the idea that the most massive stars in R136 have ZAMS masses less than about 50 $M_\odot$. To support this hypothesis, we observe that, adopting a classical IMF with a slope of -2.35, one would expect 11.2 for the ratio of the number of stars with 10 $M_\odot < M <$ 50 $M_\odot$ over those with 50 $M_\odot < M <$ 120 $M_\odot$. Applied to Figure 2, this would predict about 20 stars with $M_{130} < -11$. These stars are not observed. This is consistent with earlier results by Moffat et al. (1985), Campbell et al (1992), and Parker (1992), who conclude that R136 does not contain extraordinary massive and/or bright stars. In addition, the colors of stars R136a_1 through r136a_8 can be understood if they are either evolved blue supergiant or W-R stars. It is difficult to estimate their initial masses purely form their positions in our CMD (because all W-R stars pass through this part of the diagram), but if their progenitors had masses above $\sim$ 80 $M_\odot$, then we would expect a significant MS population in the range 50 $M_\odot < M <$ 80 $M_\odot$, as the stellar lifetime decreases with mass. Since this is not observed, it is very likely that they originate form stars of $\sim$ 50

$M_\odot$.

We conclude that the lack of extremely luminous stars in R136 is due to an intrinsic deficit of stars with ZAMS masses above $\simeq 50\ M_\odot$, if a standard Salpeter IMF is extrapolated upward from the mass interval $10\ M_\odot < M < 50\ M_\odot$. The individual components of R136a are the most luminous — and presumably amomg the most massive — stars in the R136 region. Their ZAMS masses may be as high as 80 $M_\odot$ but values around 50 $M_\odot$ are more likely.

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