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The most massive star of the largest H II region in the Small Magellanic Cloud

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Abstract. We show that the brightest star in the most important H II region of the Small Magellanic Cloud (SMC) is a multiple system. The zero-age main sequence (ZAMS) mass of this star drops significantly from the previously estimated value of 130 or 110 $M_\odot$ to less than 85 $M_\odot$ while its present mass falls from 113 $M_\odot$ to 58 $M_\odot$, both due to multiplicity and extinction correction. This is another piece of evidence against the existence of stars more massive than ~100 $M_\odot$ in the SMC. We also show that the present mass of one of the two known O 3 stars in the SMC is significantly smaller than presently believed.

Key words: clusters: open – galaxies: Magellanic Clouds – nebulae: H II regions – stars: early-type – stars: mass of – stars: spectral classification

1. Introduction

Very massive stars are considered to be the main exciting sources of giant interstellar complexes of ionized gas in galaxies. The largest and brightest complex of this kind in the Small Magellanic Cloud, called H II region N66 (Henize 1956), is excited by an extremely young star cluster, NGC 346, containing the hottest stars known in the SMC, including an O 3 star (Walborn & Blades 1986). Recently, Kudritzki et al. (1989; hereafter referred to as Kudritzki) derived a ZAMS mass of 130 $M_\odot$ for the brightest component of NGC 346 classified as O4 III (f) (Walborn & Blades 1986). However, recent results for some very massive stars in the Magellanic Clouds indicate that their masses are smaller than previously estimated (Heydari-Malayeri et al. 1988, 1989). Here we show that also this very massive star in the SMC is in fact a multiple system of at least three components with a significantly smaller mass. This result may have important implications for understanding star formation mechanisms, especially the upper limit to stellar masses which constitutes one of the fundamental problems of astrophysics, and the cosmic distance scale.

The idea of supermassive stars of about 2000 $M_\odot$ seems to be abandoned today, but the question of the exact upper limit to stellar masses remains open. Are there stars of mass greater than 100 $M_\odot$? Very massive stars should be sought towards bright, ionized nebulae. N66 is a unique object in the SMC. This giant H II region of size roughly 115 × 130 pc is excited by the very young, ~2.5 10^6 yr old (Kudritzki), open cluster NGC 346 containing about 800 stars down to a visual magnitude of 19 (Massey et al. 1989; hereafter referred to as Massey). NGC 346 is an ideal cluster for investigation of the formation and evolution of very massive stars in galaxies of low metallicity.

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2. Observations

2.1. Imaging

We obtained images of NGC 346 using the ESO New Technology Telescope (NTT) during its commissioning period on December 27, 1989 equipped with the ESO Faint Object Spectrograph and Camera (EFOSC2). The detector was a Thomson CCD (charge coupled device) chip, 1024 × 1024 pixels, each pixel 19 μm^2 (0."15 on the sky). Several broad band filters were used. The very massive star, no. 1, is indicated in Fig. 1.

In order to reduce the effects of the atmospheric turbulence, the images were restored using a deconvolution code kindly provided by Marc Remy. The point spread function (PSF) was defined by the bright stellar images on the same frame. This PSF was used to deconvolve the images on the basis of a maximum entropy method (Skilling & Bryan 1984) which proved to give very reliable results. Part of the original image showing star no. 1 is presented in Fig. 2a, while the processed image is displayed in Fig. 2b.

2.2. Photometry

The *UBV* photometry was carried out using the standard single channel photometer at the ESO 1 m telescope on December 31, 1986 and January 1st, 1987. We derive the following magnitudes for all of star no. 1: $V = 12.43$, $B-V = -0.22$, $U-B = -1.01$. The colors are in very good agreement with those of Massey, but our V is 0.14 mag brighter. Kudritzki used $V = 12.39$ (Niemela et al. 1986), which is brighter than the two other measurements (see Sect. 4 below). Here we will use our own photometric data since it is not clear whether Massey's values are already corrected for the contamination from components (*b*) and (*c*). From the intrinsic colors for O type stars (Conti et al. 1986) we derive $E(B-V) = 0.08$ mag.

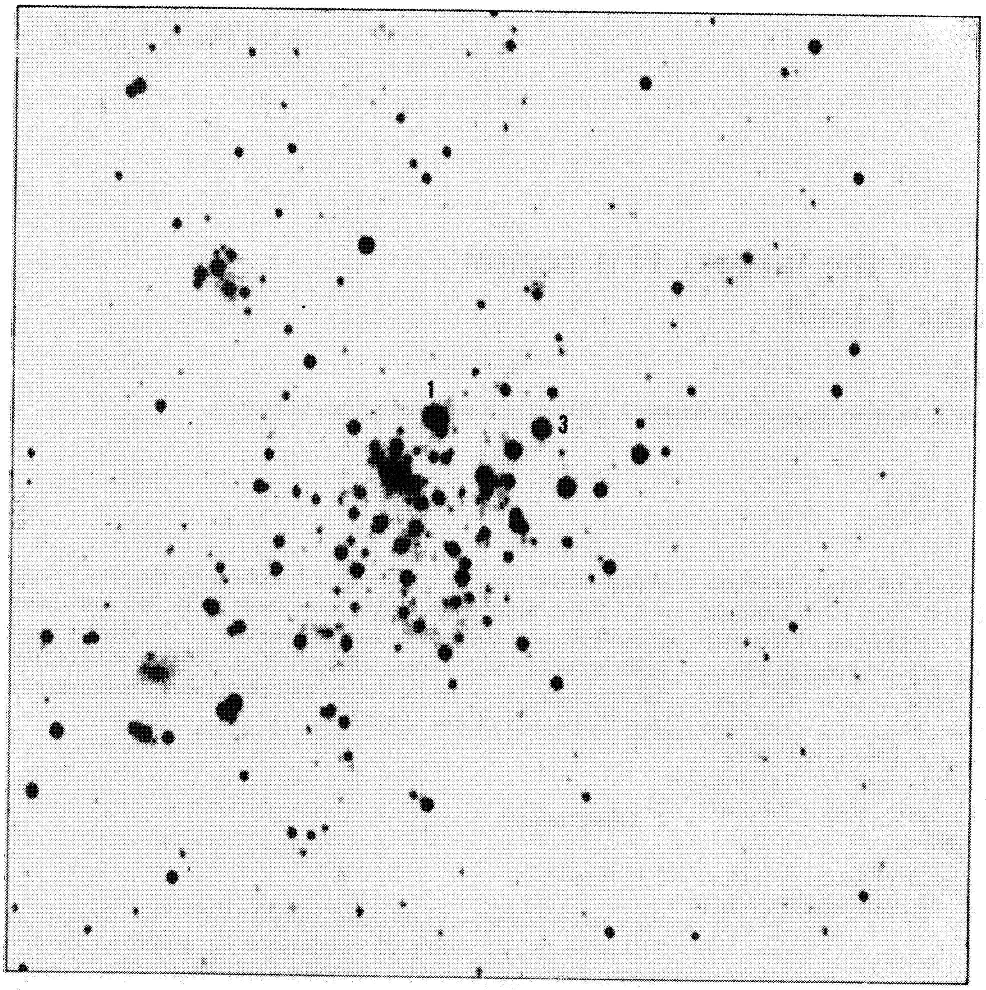

Fig. 1. The central part of the young cluster NGC 346 ionizing the giant H II region N66 in the SMC obtained using the ESO NTT with a Thomson CCD camera through an R filter. Seeing 1″.0 (FWHM). Field 165″ × 154″ on the sky. Stars no. 1 and no. 3 are indicated. North is at the top, east to the left

3. Results

The most massive member of NGC 346 (star no. 1) is for the first time clearly resolved into three components. Stars labelled (b) and (c) situated 1″.6 and 2″.6 from (a) respectively stand out conspicuously. These two components provide about 10% of the total flux of the system. Because it has a slightly elongated profile, we suspect that star (a) itself may be double with components lying less than 0″.4 apart. Note, however, that the multiplicity of star no. 1 was previously discussed by some authors. For example, Niemela et al. (1986) attributed the excessive luminosity of this star to its probable binary nature and Massay noticed a "very blended multiple image" (their Table VI). Kudritzki became aware of the multiplicity of star no. 1 in the latest stages of the publication of their paper. In a note added in proof he refers to Massey's blended image stating that their conclusions concerning star no. 1 are not affected.

Kudritzki estimated the mass by two independent methods. In the first method the profiles of hydrogen and helium lines obtained using the ESO 3.6 m telescope and the CASPEC spectrograph were compared with model calculations to determine the effective temperature ($T_{\rm eff}$), gravity (g) and helium abundance. The apparent magnitude was used to derive the absolute magnitude which, together with the fluxes of model atmospheres, gave the radius (R). Then from R and g a present mass of 113 $M_\odot$ was estimated. In the second method, from R and $T_{\rm eff}$, the luminosity (L) was derived, which compared with the evolutionary tracks of Maeder & Meynet (1987) based on Solar metallicity, gave ZAMS masses of 130 and 110 $M_\odot$ if the star lies on redward and blueward loops respectively. Kudritzki prefers the smaller value because the dispersion in age becomes smaller if star no. 1 is on the blueward loop.

We here use the same methods as Kudritzki. Let us overlook the multiplicity of (a). We derived an absolute magnitude of -6.6 for star (a) using the distance modulus of $m-M=18.9$ mag for the SMC (Westerlund 1990) and a visual extinction of $A_V=3.1\,E(B-V)=0.25$ mag. A bolometric correction (BC) of -3.93 for supergiants of type O4 (Massey) was then used to estimate a bolometric magnitude of $M_{\rm b}=-10.5$. In order to derive the present mass we adopted the values of $T_{\rm eff}$ and g given by Kudritzki for star no. 1. Using the derived $M_{\rm b}$, we calculated the luminosity, $\log(L/L_\odot)=6.1$, and then the radius, $R/R_\odot=20.0$, on the basis of the formula given by de Jager (1980). From R and g we estimate a present mass of 58 $M_\odot$ for star (a) instead of Kudritzki's 113 $M_\odot$. In the second approach, using the derived $M_{\rm b}$ and the new models of Maeder (1990) calculated for the SMC metallicity, we derived a ZAMS mass of $\sim 85\,M_\odot$ for star (a). The estimated accuracies are ~ 30% for the present mass and ~ 15% for the ZAMS mass. We did not consider the position of the star with respect to the blueward and redward loops in the

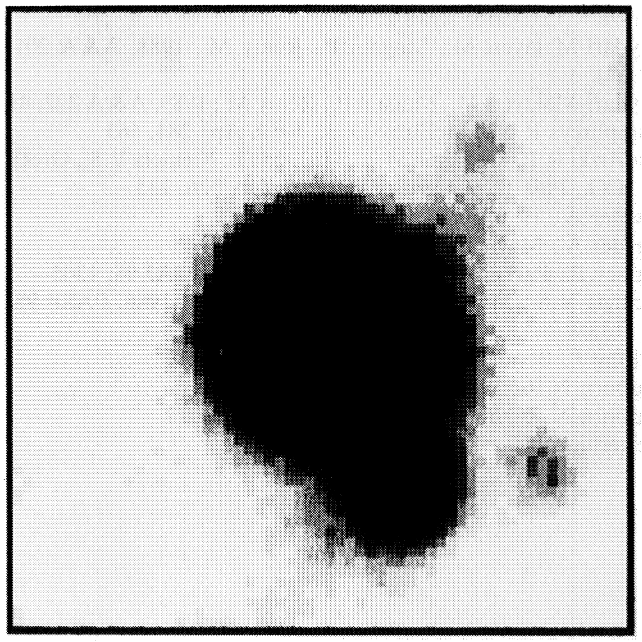

Fig. 2a. Blow-up of the very massive star no. 1 from Fig. 1. Field 9″ × 9″

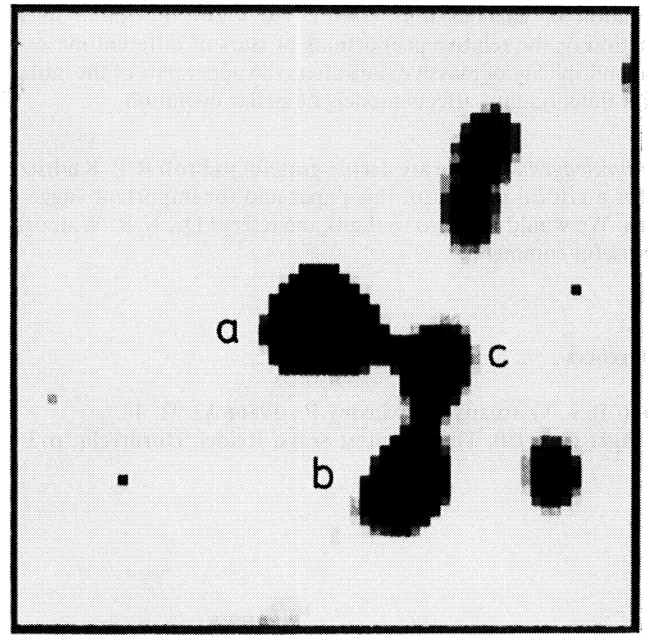

Fig. 2b. The same image after restoration. The resulting resolution is 0″.55 (FWHM)

evolutionary tracks, because in the new models the central hydrogen exhaustion occurs at lower $T_{\rm eff}$'s compared with the Solar metallicity models. We will get higher values of 66 and 90 $M_\odot$ for the present and ZAMS masses respectively if we use Kudritzki's BC = −4.1. Consequently, a ZAMS mass of ≧130 $M_\odot$ for this star is unlikely. If future observations confirm the multiplicity of star (*a*) the resulting mass will even decrease.

4. Discussion and concluding remarks

The two above-mentioned mass estimates strongly depend on accurate determination of the absolute magnitude. At present, i.e. as long as star (*a*) itself is not unambiguously resolved, the multiplicity is not the main factor in decreasing the derived mass since it contributes only 10% to the integrated apparent magnitude. Therefore, the original determination of the apparent magnitude and the extinction correction are as important. Note that Kudritzki significantly overestimated the extinction towards star no. 1. He used $E(B-V)=0.16$ mag given by Niemela et al. (1986) who, having no *UBV* observations, arbitrarily adopted the cited value. Our *UBV* observations giving $E(B-V)=0.08$ mag perfectly agree with those of Massey for star no. 1.

There are other factors affecting the resulting mass estimates, especially the bolometric correction. Kudritzki's BCs are relatively strong. We used the BCs given by Massey which are intermediate between the values of Kudritzki and those of Humphreys & McElroy (1984).

The extinction correction is crucial also far star no. 3 which with its spectral type of O3 III (f*) or O3 V ((f*)) (Walborn & Blades 1986, and Massey respectively) is one of the two hottest and most massive stars known in the SMC. Kudritzki derived ZAMS and present masses of 90 and 64 $M_\odot$ respectively using the above-mentioned large extinction and BC = −4.8. However, the *UBV* observations of Massey, i.e. $V=13.50$ (0.07 mag fainter than the V used by Kudritzki) and $E(B-V)=0.07$ (practically the same as for no. 1), along with their BC = −4.36 corresponding to O3 main sequence give ZAMS and present masses of ∼77 and 28 $M_\odot$. The use of Kudritzki's BC = −4.8 gives masses of 90 and 40 $M_\odot$ respectively.

It is noteworthy that star no. 3 while hotter than star no. 1 is much fainter in M_V. Kudritzki ascribes this to the bolometric correction and evolution. He argues that mass loss on time scales probably short compared with that of the starburst can produce an extreme supergiant like star no. 1, whereas star no. 3 is a main sequence star either newly born or recontracting. However, star no. 1 is not an extreme supergiant since, as we showed, it has a ZAMS mass of at most ∼85 $M_\odot$. We think that the possible multiplicity of component (*a*) may be the main reason for the luminosity difference between stars no. 1 and no. 3.

Recently, star no. 1 was classified by Massey as O5.5 If. The difference with respect to Walborn & Blade's (1986) spectral type of O4 III (f) is, according to Massey, due to multiplicity. Since components (*b*) and (*c*) are faint with respect to (*a*), Massey's result favors the multiplicity of component (*a*). However, the difference between the classifications may also be due to variability or simply better S/N ratio. Note also that the derived absolute magnitude of −6.6 (Sect. 3) is in good agreement with calibration for single stars of this type (Walborn 1973). In any case, it will be very interesting to check the multiplicity of component (*a*) with high resolution imaging observations.

The present results give another blow to the idea of stars more massive than ∼100 $M_\odot$ in the SMC. We confirm Massey's conclusion that the most massive stars in NGC 346 appear to have ZAMS masses of 70–85 $M_\odot$. If spatial resolution is already so crucial for our nearest companion galaxies, the Magellanic Clouds, it will be even more decisive for galaxies at greater distances. Star formation processes probably create much less massive stars than inferred from a simple analysis of low resolution observations. However, in order to understand the evolution of galaxies it is essential to know the initial mass function or the relative proportions of stars of different masses. The multiplicity of massive stars alters the upper part of the initial mass function and affects models of stellar evolution.

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