The massive stellar population in the young association LH 95 in the Large Magellanic Cloud

N. Da Rio,1⋆ D. A. Gouliermis,2,3 B. Rochau,2 A. Pasquali,4 J. Setiawan2 and G. De Marchi1

1European Space Agency, Keplerlaan 1, 2200 AG Noordwijk, the Netherlands
2Max Planck Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
3Zentrum für Astronomie der Universität Heidelberg, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, 69120 Heidelberg, Germany
4Zentrum für Astronomie der Universität Heidelberg, Astronomisches Rechen-Institut, Mönchhofstr. 12-14, 69120 Heidelberg, Germany

Accepted 2012 February 29. Received 2012 February 29; in original form 2012 January 23

ABSTRACT

We present a spectroscopic study of the most massive stars in the young (4 Myr old) stellar cluster LH 95 in the Large Magellanic Cloud. This analysis allows us to complete the census of the stellar population of the system, previously investigated by us down to 0.4 M⊙ with deep Hubble Space Telescope Advanced Camera for Surveys photometry. We perform spectral classification of the five stars in our sample, based on high-resolution optical spectroscopy obtained with the 2.2-m MPG/ESO Fibre-fed Extended Range Optical Spectrograph. We use complementary ground-based photometry, previously performed by us, to place these stars in the Hertzsprung–Russell diagram. We derive their masses and ages by interpolation from evolutionary models. The average ages and age spread of the most massive stars are found to be in general comparable with those previously derived for the cluster from its low-mass pre-main-sequence stars. We use the masses of the five sample stars to extend to the high-mass end the stellar initial mass function of LH 95 previously established by us. We find that the initial mass function follows a Salpeter relation down to the intermediate-mass regime at 2 M⊙. The second most massive star in LH 95 shows broad Balmer line emission and infrared excess, which are compatible with a classical Be star. The existence of such a star in the system adds a constrain to the age of the cluster, which is well covered by our age and age spread determinations. The most massive star, a 60–70 M⊙ O2 giant, is found to be younger (<1 Myr) than the rest of the population. Its mass in relation to the total mass of the system does not follow the empirical relation of the maximum stellar mass versus the hosting cluster mass, making LH 95 an exception to the average trend.

Key words: stars: early-type – stars: luminosity function, mass function – stars: massive – open clusters and associations: individual: LH 95 – Magellanic Clouds.

1 INTRODUCTION

It is well established (Lada & Lada 2003) that the vast majority of stars are not formed in isolation, but as part of stellar associations and clusters. These comprise hundreds or even thousands of stars along the entire mass spectrum, from the most massive OB-type stars down to low-mass late-type stars. The study of young (few Myr old) clusters, therefore, provides a fundamental tool to understand how the star formation process takes place. Both high- and low-mass stars are, from different points of view, of complementary importance in such clusters. On the one hand, the short-lived massive stars are the direct evidence of the youth of these systems, and their energy output through winds and ultraviolet (UV) radiation is responsible for the gas removal, a process that strongly affects the survival of the stellar system. On the other hand, the low-mass stars constitute the majority of the newly formed stellar population, and their slow evolution during the pre-main-sequence (PMS) phase traces the time-scale of star formation.

The study of star-forming regions in the Milky Way is affected by the high extinction produced by the dust in the Galactic disc, limiting the depth of optical observations. This problem does not affect significantly studies in the Magellanic Clouds (MCs), our nearby metal-poor dwarf galaxies. Both the Large and Small Magellanic Clouds (LMC and SMC, respectively) are characterized by an exceptional sample of star-forming regions, the H II regions (Henize...
1956; Davies, Elliott & Meaburn 1976), where hydrogen is already being ionized by the UV winds of massive stars. A plethora of young stellar associations and clusters are embedded in these regions (e.g. Bica & Schmitt 1995; Bica et al. 1999), giving evidence of current clustered star formation.

LH 95 (Lacke & Hodge 1970) is a young stellar cluster in the LMC related to the H II region LHA 120-N 64 (Henize 1956), located to the north-east of the superbubble LMC 4. The association has a projected size of ~10 x 20 pc, and is not centrally concentrated but presents at least three main subclusters. Its stellar population has been studied by Gouliermis et al. (2002) using ground-based BVR and Hα photometry; they determined the initial mass function (IMF) from 30 to 2 M⊙. More recently, very deep Hubble Space Telescope Advanced Camera for Surveys (HST/ACS) observations in F555W and F814W bands (Gouliermis et al. 2007) led to the discovery of a population of ~2500 PMS stars in the region. In Da Rio, Gouliermis & Henning (2009, hereafter Paper I), using these data, we derived the first extragalactic IMF in the subsolar regime, complete down to ~0.4 M⊙ while members have been detected with masses as low as 0.2 M⊙. Later, in Da Rio, Gouliermis & Gennaro (2010, hereafter Paper II), we investigated the age and age spread of the intermediate- and low-mass stars in LH 95 through a statistical technique that accounts for physical and observational biases in the observed colours and magnitudes. We found an average age of the system of the order of 4 Myr, and an age spread well represented by a Gaussian distribution with a standard deviation of 1.2 Myr.

Despite the large luminosity (and mass) range spanned by our ACS observations, our stellar sample was incomplete to the high-mass end, since five of the brightest stars were saturated in the HST images. Moreover, optical photometry of high-mass stars (with M > 8 M⊙) alone is not sufficient for the accurate derivation of their stellar parameters. This is because these stars, due to their high effective temperatures T_eff, emit a large fraction of their flux in the UV wavelength range. As a consequence, the optical bands are in the Rayleigh regime and the observed colours tend to be independent of T_eff. This well-known problem was made evident also in Paper II, where we demonstrated that dating massive stars based only on their photometry is highly uncertain.

Stellar parameters of massive stars can be determined accurately through spectroscopy. Therefore, in order to study the brightest stellar members of LH 95, and to construct the Hertzsprung–Russell (HR) diagram of its massive stellar population, we perform here a spectroscopic follow-up to our previous studies. We acquired optical spectra of the five brightest stars in the region and we complemented these data with existing BVR photometry of LH 95, obtained from the ground (Gouliermis et al. 2002). The aim of this investigation is twofold: (1) the completion of the IMF derived in Paper I towards the highest masses and (2) the analysis of the ages of the high-mass members (and possible variations), in relation to the similar results we presented in Paper II for the low-mass population.

This paper is organized as follows. The spectroscopic observations and their data reduction are described in Sections 2 and 3. In Section 4 we present the classification of the sources. In Section 5 we derive the HR diagram for the high-mass end of the LH 95 population, and assign ages and masses to the sources. A discussion on these results is presented in Section 6, and in Section 7 we discuss the high-mass end of the IMF. We then focus in Section 8 on the brightest source in the sample, where we present evidence that classifies it as a classical Be star. Finally, in Section 9 we summarize the main findings of this paper.

2 THE OBSERVATIONS

This spectroscopic study focuses on the brightest stellar sources in LH 95, which were saturated in our HST/ACS images. For the photometry of these sources we use the measurements by Gouliermis et al. (2002), based on BVI ground-based observations. While this photometric study achieved significantly shallower detection limits and poorer spatial resolution than our ACS imaging, it provides accurate BVI photometry for all the bright sources within the star-forming region. Based on this study we excluded from our analysis the bright stars with significantly red colours, as probably being field red giant branch (RGB) stars. This is because at the age of LH 95 (~4 Myr), the turn-off from the main sequence occurs at a large mass (~40 M⊙), and the RGB stars above this mass are not expected to have temperatures lower than 6000 K (Schaerer et al. 1993; Girardi et al. 2002) and thus should not show very red optical colours. The remaining five bright main-sequence stars are the targets of this spectroscopic follow-up. We annotate these sources with the letters A, B, C, D and E in the colour-composite VJ image of our HST/ACS observations, shown in Fig. 1 (left-hand panel). The B − V, V colour–magnitude diagram (CMD) from the photometric study of Gouliermis et al. (2002) is shown also in Fig. 1 (right-hand panel). In this plot, stars identified by Gouliermis et al. (2002) in a significantly larger field of view (FOV) than that of ACS are plotted with grey symbols. The stars observed within our ACS FOV (Gouliermis et al. 2007) are highlighted with large black symbols and the targets of this spectroscopic study with red symbols. They are also annotated in this CMD with their alphabetic IDs.

The observations have been carried out with the Fibre-fed Extended Range Optical Spectrograph (FEROS), mounted on the 2.2-m MPG/ESO telescope located at the La Silla Observatory in Chile. This instrument has a resolution of R = 48 000 and a wavelength coverage of 3600–9200 Å (Kaufer & Pasquini 1998). The spectrograph is fed by two fibres with an aperture of 2.0 arcsec, providing simultaneous spectra of a stellar target, plus either the sky or one of two calibration lamps (wavelength calibration and flat-field). Since for our purposes the wavelength calibration is not critical, we used the ‘OBJSKY’ instrument set-up, acquiring a position in the sky in parallel to the targets separated by 2.9 arcmin. The necessary calibration acquisitions have been carried out separately for each observing night. Observations were carried out in two epochs: 2008 November and 2009 January. The summary of the observations is given in Table 1. Multiple spectra have been taken for the same targets to enable cosmic ray detection and removal. The overall exposure times have been higher for fainter sources in order to reach a sufficient signal-to-noise ratio (S/N). Specifically, our final spectra reach an average S/N in the optical range spanning from ~100 for star A to ~30 for star E.

3 DATA REDUCTION

The basic data reduction of the spectra was performed by using the automatic online pipeline. This pipeline extracts the 39 cross-dispersed spectral orders and combines them together in a single, wavelength-calibrated, spectrum. We manually subtracted the relevant sky emission from each spectrum; then we normalized the continuum of each spectrum to unity by fitting a high-order polynomial to the continuum smoothed with a median filter 12 Å in size. Each derived continuum has been visually inspected together with its original spectrum to ensure a correct estimation. The continuum normalization also allows us to correct for shape variations in the

© 2012 The Authors, MNRAS 422, 3356–3369
Monthly Notices of the Royal Astronomical Society © 2012 RAS
spectra of the same star introduced by changes in airmass and atmospheric extinction, as well as flux factors due to different exposure times. Cosmic rays are detected as $>3\sigma$ peaks above the continuum on each spectrum and absent in the other spectra of the same star. The average local noise, $\sigma$, was computed in a 2-Å neighbourhood of each wavelength point. The cosmic rays were then masked, and the spectra were combined in one final spectrum with the use of a weighted average method, accounting for the individual exposure times. In order to facilitate the spectral classification, the original spectra were also degraded to a resolution of 1 Å.

The blue wavelength range of the final spectra is presented in Fig. 2. In this plot the spectra are blueshifted by an amount $\delta\lambda/\lambda = 10^{-3}$, to correct for the radial velocity (RV) of the system, $v_r \approx 302.8 \text{ km s}^{-1}$, determined from the lines in the spectra. For the four faintest stars, we have manually removed part of the spectra at $4695 \leq \lambda \leq 4720$ Å, where an artificial feature in emission

\begin{table}
\centering
\caption{Summary of the observations.}
\begin{tabular}{lcccccccc}
\hline
ID & ID2 (G02)$^a$ & Alternative name$^b$ & RA (J2000.0) & Dec. (J2000.0) & $V$ (mag) & Exposure time (s) & Airmass & Epoch \\
\hline
A & 9136 & SK-66 170 & 05:36:58.945 & $-66:21:16.130$ & 13.17 & 3600 & 1.31 & 2008 November \\
 & & & & & & 1000 & 1.35 & 2008 November \\
 & & & & & & 1500 & 1.39 & 2008 November \\
 & & & & & & 1200 & 1.26 & 2009 January \\
 & & & & & & 1200 & 1.25 & 2009 January \\
B & 9141 & SK-66 172 & 05:37:05.553 & $-66:21:34.950$ & 13.58 & 900 & 1.32 & 2008 November \\
 & & & & & & 900 & 1.27 & 2008 November \\
C & 9143 & SK-66 174 & 05:37:15.723 & $-66:21:38.355$ & 13.74 & 900 & 1.28 & 2008 November \\
 & & & & & & 900 & 1.28 & 2009 November \\
D & 18 & & 05:36:58.007 & $-66:21:42.613$ & 14.53 & 1400 & 1.28 & 2008 November \\
 & & & & & & 1400 & 1.31 & 2008 November \\
 & & & & & & 1400 & 1.34 & 2008 November \\
 & & & & & & 1800 & 1.31 & 2009 January \\
E & 85 & & 05:37:15.129 & $-66:21:44.304$ & 15.58 & 1800 & 1.35 & 2009 January \\
\hline
\end{tabular}

$^a$Catalogue numbers of Gouliermis et al. (2002).

$^b$Sanduleak (1970) identification numbers.
The massive stellar population in LH 95

Figure 2. Reduced spectra for the five targets, covering the violet–blue range of the spectrum, relevant for spectral classification of early-type stars. The main stellar lines we have identified in the spectra are indicated as well. The features identified in the spectra are the following: He\textsc{I} λ\lambda 4009, 4026, 4121, 4144, 4387, 4471, 4713; He\textsc{II} λ\lambda 4200, 4541, 4686; C\textsc{III}/O\textsc{II} λ 4070; Si\textsc{IV} λ\lambda 4089–4116; Si\textsc{III} λ\lambda 4552–4568–4575; N\textsc{II} λ 3995; N\textsc{III} λ\lambda 4097, 4634–4640–4642; N\textsc{IV} λ 4058; N\textsc{V} λ\lambda 4604–4620; O\textsc{II} λ 4415; C\textsc{III} λ\lambda 4647–4650–4652.

dominates the continuum of the 16th spectral order. By visual inspection on the individual spectral orders, we verified that the He\textsc{II} λ 4686 line is not affected by this artefact, being located at the red end of the 15th order.

4 SPECTRAL CLASSIFICATION

We assign spectral types to our targets by comparing their spectra to stellar atlases available in the literature. In particular we consider the atlases of Walborn & Fitzpatrick (1990) and Sota et al. (2011), which contain a large selection of early-type stars and provides a fine coverage of the spectral types and luminosity classes of OB stars. We also use the atlases of OB-type stars of Walborn et al. (1995) and Walborn et al. (2002). Based on our classification, we assume an uncertainty in the assigned spectral types of half a spectral subtype for stars A to D and one subtype for star E.

Star A

This is the brightest stellar source in the region (V \sim 13.5 mag; Gouliermis et al. 2002). Due to the long total exposure time allocated to this source (exceeding 2 h) the derived spectrum reaches a very high S/N (> 100). The line ratio between He\textsc{I} λ 4471 and He\textsc{II} λ 4541, together with the ratio Si\textsc{III} λ 4552/Si\textsc{IV} λ 4089, indicates a B0.2-type star. As far as its luminosity class is concerned the spectrum of this star shows some inconsistencies. In particular, while the significant strength of the Si\textsc{IV} lines suggests a very luminous star of class I or II (also considering the low metallicity of the LMC), the presence of the He\textsc{II} λ 4686 line is consistent only with a luminosity class IV
or V. Therefore, we assign to this source a giant luminosity class and we classify this star as a B0.2 IIIp. As we discuss later (see Section 8) this star shows prominent Hα and Hβ emission, behaving as a classical Be star.

**Star B**

This star was already classified by Walborn et al. (1995) as an O3 III(f*), and then reclassified in Walborn et al. (2002) as O2 III(f*), with evidence in support of a binary system with a later OB-type star. Our spectrum confirms this classification, mainly based on the prominent N IV λ4058 emission, the NV λλ4604–4620 absorption and the absence of N III λλ4640 emission. The significant strength of the N IV λ4058 line indicates a luminous star (<III), but the He II λ4686 in absorption excludes a supergiant. According to Walborn et al. (2002), the spectrum is a composite including an unresolved later type star, as revealed by the detection of the He II λ4471. In our spectrum (see Fig. 2) we also clearly detect He II λ4387, which did not appear in the Walborn et al. (1995) spectrum. This further supports the claim that this source is a composite system. For an additional discussion on the composite nature of this source, we refer the reader to Section 6.1.1.

**Star C**

According to the ratio between He II λ4541 and He II λ4471 (which are equally strong for O7 stars) this source is an O7.5 type. The presence of N III λλ4634–4640–4642 emission is typical of a luminous star of this spectral type, and their strength suggests at least a III(f) luminosity class. The strong N III λ4097 absorption is also supportive of a bright giant. We also note a modest emission in C III λλ4647–4650–4652, which is atypical for this spectral type. The strength of the He II λ4686 absorption is in contrast to the N III emission, indicating a luminosity not higher than class III. We argue that the unusual strength of the N emission lines might be due to nitrogen enrichment or, alternatively, could be indicative of a composite nature for this source. As a compromise, we classify this star as O7.5 III(f).

**Star D**

The ratio between He II λ4541 and He II λ4471 indicates a type of O6.5 for this star. In addition, the presence of strong He II λ4686 absorption, typical of main-sequence O-type stars, leads to the classification of this star as an O6.5 V.

**Star E**

Given the strength of the He I and the absence of He II lines, this source is an early B-type star. The strength of Si IV and Si III, together with the absence of Si II λλ4128–4130, indicates a B1.5 star. The additional presence of N II λλ3995 suggests a luminous star, but not a supergiant given the absence of several indicators of such high luminosity (e.g. strong O II lines). Therefore we assign the spectral type B1.5 III.

**5 THE HR DIAGRAM**

In this section we derive the stellar parameters of the observed sources from both our spectroscopic analysis described above and the available photometric measurements of these sources (Gouliermis et al. 2002), and we construct the HR diagram for these stars. We consider appropriate temperature scales for early-type stars with LMC metallicity ([Fe/H] < −0.3; Luck et al. 1998), and we derive the effective temperatures (T_{eff}) of the stars from their spectral types. There is a number of spectral type–T_{eff} conversions available in the literature, covering different ranges in the parameter space. The derivation of such relations usually relies on model stellar atmospheres, in which T_{eff} is an input parameter. The associated spectral types are obtained from the presence of diagnostic lines, following observational criteria such as those we applied in the previous section.

The stellar atmosphere modelling in particular for O-type stars is quite challenging (see e.g. Kudritzki & Puls 2000), since it requires several factors to be considered for the effects of metals in the atmospheric structure and emergent spectrum, such as a non-local thermodynamic equilibrium treatment, spherical expansion due to stellar winds and line blanketing (Martins, Schaerer & Hillier 2005). Such studies show a clear dependence of the temperature scale on the luminosity class, with luminous stars being cooler than dwarfs at a given spectral type. In addition, Massey et al. (2005) found evidence for a systematic change in the temperature scale with metallicity. They collected high S/N optical and UV spectra of a sample of O-type stars in the Galaxy and in the MCs, and derived the stellar T_{eff} via modelling. These authors found that SMC O-type stars are systematically hotter than Galactic stars at the same spectral type, while LMC stars follow an intermediate-temperature scale between the two, as expected by their metallicity. In agreement with previous works, they also found lower T_{eff} for supergiants (luminosity class I), while no significant differences were measured between giants and dwarfs (III and V).

Considering these results, for the late O-type stars in our sample we adopted the Massey et al. (2005) LMC scale, which covers the range O3–O9.5. Temperatures are not explicitly provided for O2 stars, but the sample of Massey et al. (2005) includes two LMC O2 III stars, to which they assign a lower limit of T_{eff} = 48 000 K, and two O2 V with temperatures between 51 000 and 55 000 K. Based on these measurements, we assign a T_{eff} = 50 000 ± 2000 K to our O2 III star. This value is also compatible with the Massey V+III scale extrapolated to O2 stars and in agreement with other O2 giant stars in the LMC (e.g. Evans et al. 2010). For the two early B-type stars, we adopt the temperature scale of Bessell, Castelli & Plez (1998), which matches very well the Massey scale at B0. We note that for B-type stars, the uncertainties in the spectra modelling become less prominent. This is supported by the fact that all the recent temperature scales for O-type stars (e.g. Vacca, Garmany & Shull 1996; Martins, Schaerer & Hillier 2005; Massey et al. 2005) are in agreement with each other at the O–B transition predicted at T_{eff} ≃ 30 000 K, whereas they present significant differences at higher T_{eff}. Moreover, in the B-type range we do not expect any significant dependence of the T_{eff} scale on metallicity, as shown by Massey et al. (2005).

We derive the bolometric luminosities of our stars by first correcting our V magnitudes for extinction and then applying bolometric corrections according to the stellar temperatures. Extinctions are estimated from the E(B − V) colour excess in the photometry of Gouliermis et al. (2002). We use the intrinsic (B − V)$_{0}$ colours published by Martins & Plez (2006) for O-type stars and by Bessell et al. (1998) for B-type stars. Since O-type stars are well into the Rayleigh–Jeans regime at optical wavelengths, the intrinsic colours are hardly sensitive on T_{eff}. According to Martins & Plez (2006), (B − V)$_{0}$ decreases from 0.28 mag to only 0.26 mag in the entire O spectral class, with differences between luminosity classes less...
The massive stellar population in LH 95

Table 2. Derived stellar parameters for our target stars.

| ID   | $T_{\text{eff}}$ (K) | $BC_V$ (mag) | $A_V$ (mag) | log $L/V$⊙ | Mass⊙ | Age (Myr) |
|------|----------------------|--------------|-------------|------------|-------|-----------|
| A    | 29170±270            | −2.816±0.066 | 0.880 ± 0.174 | 5.474±0.026±0.07 | 33.2 ± 2.7 | 5.43 ± 0.41 |
| B    | 50000±2000           | −4.433±0.118 | 0.644 ± 0.174 | 5.862±0.047±0.07 | 72.1 ± 6.9  | 0.33 ± 0.18 |
| C    | 35480±650            | −3.407±0.057 | 0.464 ± 0.174 | 5.316±0.023±0.07 | 31.0 ± 2.1  | 4.55 ± 0.18 |
| D    | 38110±610            | −3.620±0.058 | 0.433 ± 0.174 | 5.073±0.020±0.07 | 26.8 ± 1.3  | 2.05 ± 1.1  |
| E    | 24380±1990           | −2.436±0.340 | 0.982 ± 0.174 | 4.396±0.136±0.07 | 13.0 ± 1.1  | 14.7 ± 2.5  |

$a$The first error in log $L/V$⊙ represents the propagation of the uncertainty in log $T_{\text{eff}}$ (and consequently in BC); the second error represents the propagation of the uncertainty in $M_V$.

$b$The masses and ages of the stars are determined in Section 5.1.

than 0.01 mag. Subsequently, we also assume that metallicity variations do not affect the intrinsic $(B - V)$ colour. For the two early B-type stars in our sample we consider the intrinsic colours from Bessell et al. (1998), assuming log $g = 4.0$. According to this study, at the $T_{\text{eff}}$ of early B-type stars, changes in surface gravity of more than 1 dex cause very small variations of $(B - V)_0$, of the order of 0.01 mag. As a consequence, the uncertainties in the luminosity classes of sources A and E are not expected to bias in any way the assumed intrinsic colours of the two stars, and thus the derived optical extinction.

The measured colour excess $E(B - V)$ is then converted into $A_V$ assuming the average LMC reddening law $R_V = 3.41 ± 0.06$ (Gordon et al. 2003), a value slightly higher than the typical Galactic, $R_V = 3.1$ (Cardelli, Clayton & Mathis 1989). The photometric errors in $B$ and $V$ are negligible, given the high luminosity of the bright members of LH 95. Nevertheless, we add a constant 0.035-mag uncertainty to every star in each band, representing the precision of the photometric calibration of Gouliermis et al. (2002). Therefore, the derived $E(B - V)$ has an error of 0.05 mag. We convert the extinction-corrected magnitudes, $V_0$, into absolute magnitudes, $M_V$, considering a distance modulus $(m - M)_0 = 18.41$ mag (Paper I).

Finally, we convert absolute magnitudes into total stellar luminosities (log $L/L_{\odot}$) by applying the appropriate V-band bolometric corrections ($BC_V$). For our O-type stars we use the relation from Massey et al. (2005):

$$BC = 27.99 - 6.90 \log T_{\text{eff}}.$$ 

Clearly, as for the intrinsic colours, these authors found BCs to be mainly dependent on temperature and independent of luminosity. Also, they found good agreement with the BCs derived from previous works (Vacca et al. 1996). A comparison of this relation with the bolometric corrections of Martins et al. (2005) yields differences below 2 per cent. For the BCs of B-type stars, we consider again the values from Bessell et al. (1998).

Star A, as we describe in detail in Section 8, appears to be a Be star, showing prominent H$\alpha$ and H$\beta$ emission. This excess, however, does not affect our derived stellar parameters for this star. The H$\alpha$ line is at wavelengths longer than the V-band bandpass; on the contrary, H$\beta$ is inside the B-band throughput. As we show in Fig. 9, however, this line emission appears to be modest, with an equivalent width (EW) of $\sim$2.8 Å. This is small compared to the EW of the B-band filter profile, which is $\sim$912 Å. Furthermore, at the H$\beta$ wavelength ($\lambda = 4861$ Å) the filter throughput is about 40 per cent its peak. As a consequence, the line emission we detect for this star produces a measured flux excess in our B-band photometry of the order of 0.1 per cent or 0.001 mag. This is therefore absolutely negligible for the derivation of the $A_V$ from the $E(B - V)$ colour excess.

We derive the bolometric luminosity from the relation

$$\log L/L_{\odot} = 0.4(M_{\text{bol,c}} - M_V - BC_V),$$

where $M_{\text{bol,c}} = 4.75$ is the absolute bolometric magnitude of the Sun. The parameters derived for our five stars in this section are given in columns 1–4 of Table 2. The positions of the stars in the HR diagram, as well as the errors due to both $T_{\text{eff}}$ uncertainties (diagonal error bars) and photometry (vertical error bar), are shown in Fig. 3. In the same plot we overlay a set of Geneva evolutionary models for the LMC metallicity ($Z = 0.008$). These are from Schaerer et al. (1993) and are computed assuming no stellar rotation. In general, however, stellar rotation plays an important role in the evolution of massive stars (Maeder & Meynet 2000) by enhancing mass loss, introducing anisotropy, introducing transport of angular momentum and mixing of chemical elements in radiative zones. While these effects influence the stellar evolution in the HR diagram (Meynet & Maeder 2000), they are critical mainly for the evolved stages of massive stellar evolution, and in particular the Wolf–Rayet phase (Meynet & Maeder 2003) and the final pre-supernova stages (Hirschi, Meynet & Maeder 2004). In Fig. 3 we also plot with dashed lines evolutionary tracks from the grid of models by Schaerer et al. (1993) for selected stellar masses. Unfortunately, there are no evolutionary models considering rotation, which are available for the metallicity of the LMC and for the entire high-mass stellar range, except of those computed by Meynet & Maeder (2005) for masses of 40, 60 and 120 $M_{\odot}$, which include an assumed rotation of $v_{\text{rot}} = 300$ km s$^{-1}$. We show also these tracks in Fig. 3 with green dotted lines. For clarity we have not plotted the evolved stages for these masses. From the comparison between the two families of tracks shown in the figure, it is evident that, at the HR diagram positions of our five stars, the consideration of rotation or not does not affect significantly the derived stellar parameters.

5.1 Masses and ages of the stars

Considering the above, we utilize the grid of Schaerer et al. (1993) and assign masses and ages to our stars by interpolation. A particular attention was given to the evaluation of the uncertainties associated with these parameters. As shown in Fig. 3, the errors in log $T_{\text{eff}}$ and log $L$ are correlated and asymmetric. Moreover, the probability for the star to be measured in different positions of the HR diagram within the error may not be uniform. This is, for example, the case of source E, the measured log $T_{\text{eff}}$ and log $L$ of which are located over the H-exhaustion locus of the evolutionary models, i.e. the
Figure 3. HR diagram of the selected targets, together with evolutionary tracks for initial masses between 10 and 120 M\(_{\odot}\) (dashed lines) and isochrones for ages between 0.4 and 40 Myr (solid lines) from the Geneva models of Schaerer et al. (1993) for LMC metallicity. The dotted lines are evolutionary models for stars with rotation, for masses of 40, 60 and 120 M\(_{\odot}\) and LMC metallicity, from Meynet & Maeder (2005).

turnaround feature of all the isochrones and tracks in the figure at log \(T\) \(\sim\) 4.4. After the H-exhaustion, the evolution of a star is much faster in the HR diagram, and thus the chance of detecting a star at colder temperatures than this point is significantly lower than at hotter temperatures. We take into account this effect to normalize our results by introducing a prior to the estimation of the masses of our targets.

In order to evaluate the most probable masses and ages for our stars, we proceed with the application of a Monte Carlo technique, as we describe in the following paragraphs. First, we construct the two-dimensional density distribution of the relative rapidity of stellar evolution on the HR diagram. For this construction we interpolate the original grid of isochrones and tracks of Schaerer et al. (1993) on to a dense grid with uniform spacing in mass and age. For every point in the new grid, the relative speed of evolution is proportional to the inverse of the distance, on the same track, between neighbouring points. This distance depends on the assumed metric, for which we choose a linear scale for both axes of the HR diagram. Since we are interested in the relative variation of evolution speed between different points in the HR diagram, the units chosen in both axes to derive the distance between points are arbitrary and equivalent. Then, for each of our five stars, we generate a well-populated number of test stars distributed within the errors shown in Fig. 3. We assume a flat distribution in log \(T\), with an equal number of stars on both sides from the central temperature, and a Gaussian distribution in log \(L\), keeping the correlation between the two quantities (the diagonal error bars) as shown in Fig. 3. For each of these simulated stars we assign masses and ages by interpolation on the grid of models, as well as the exact value of relative speed of evolution. Finally, we derive the best mass and age, as well as the uncertainties of these quantities, using weighted statistics, where the weight is the inverse of the evolutionary rapidity. The results are illustrated in Fig. 4, each panel of which represents the mass–age distribution of each of our target stars colour coded according to the weights.

We summarize our results in columns 5 and 6 of Table 2, where we give the most probable masses and ages, and their associated uncertainties for our stars. The influence of weighting the derived stellar parameters on the evolution time-scales is evident for stars B and E. For star B, the method tends to favour a slightly younger age than the central value of \(\sim\)0.4 Myr shown in Fig. 3, while its mass is not significantly affected. For star E, the large uncertainty on the HR diagram leads to a correlation in the mass–age plane, predicting either a younger more massive star or an older less massive star. Nevertheless, the latter case is less probable than the former, leading to an estimate of the most likely mass of \(M = 13 M_\odot\). This value is larger than that one would obtain by neglecting the errors in the HR diagram, i.e. \(\sim 12 M_\odot\) (see Fig. 3).
Figure 4. Illustration of the Monte Carlo method to derive the stellar mass and age as well as the associated uncertainties, accounting for the evolution speed in the HR diagram as a weighting quantity. For every star, the dots represent the transformation in the mass–age plane of the simulated population of stars within the error bars in the HR diagram. The colour is proportional (from dark to light blue) to the rapidity of evolution in the HR diagram. The crosses represent the derived mean parameters, weighted according to the inverse of the rapidity of evolution.

6 DISCUSSION ON THE DERIVED AGES

6.1 Stellar multiplicity

The stellar parameters derived in the previous section might be biased by the presence of unresolved companions. In fact, most of the early-type stars are expected to be formed in binary systems (Lada 2006), with a binary fraction of the order of 60–100 per cent (Zinnecker & Yorke 2007). Given the distance of the MCs, binary systems generally cannot be resolved.

As mentioned in Section 4, for star B, we have evidence from the spectrum of an unresolved later type companion. For the other sources, we are unable to confirm stellar multiplicity based on our spectroscopy. Considering that our spectroscopic observations for stars A, D and E were performed in two epochs, with a time baseline of ~2 months, we attempted to detect evidence of binarity through any RV variations for these stars. We computed the stellar radial velocities, using the cross-correlation technique of Baranne et al. (1996). Each stellar spectrum was cross-correlated with a numerical template that was built from the stellar spectrum itself by selecting certain spectral lines. For this propose we rejected blended absorption lines. We used six absorption lines for star A and obtained an accuracy of ~2 km s\(^{-1}\). A similar accuracy was also obtained for stars D and E, where we selected four absorption lines. While we observed no significant RV variation in stars A and E during the two epochs (2008 November and 2009 January), we detected a linear trend in the RV variation of star D during this time window. The RV variation between the second (2009 January) and the first epoch (2008 November) is ~9 km s\(^{-1}\). This RV variation can be caused by stellar activity or the presence of an unseen stellar companion.

We study now in more detail how unresolved multiple systems can affect our derived masses and ages, and distinguish two cases.

(1) The optical luminosity of the companion is significantly smaller than that of the primary. In this case, both the measured spectral type and the optical magnitude are representative of the primary, and thus also the position of the star in the HR diagram. The presence of the companion, therefore, does not alter the derived parameters of the primary, but affects only the completeness of the stellar sample.

(2) The optical luminosity of the companion is comparable to that of the primary. In this case, both the measured spectral type and the optical magnitude are representative of the primary, and thus also the position of the star in the HR diagram. The presence of the companion, therefore, does not alter the derived parameters of the primary, but affects only the completeness of the stellar sample.

(a) The two stars have identical spectral type: this implies that they are identical companions. They would be located in the HR diagram at the same \(T_{\text{eff}}\) we have determined through spectroscopy and 0.3 dex fainter in \(\log L\). (b) The two stars have different spectral types. The spectral type we have determined from spectroscopy will be roughly the average of the individual spectral types of the two stars. This scenario, however, would be unrealistic. This is clarified in Fig. 5, where we simulate this effect on star C. The two companions with identical optical luminosity but \(T_{\text{eff}}\), respectively,
only major anomaly in the spectrum is the He I lines, we argue that the secondary is an early B-type star. By comparing the relative strength of the He I lines with respect to the continuum, and considering that the other lines from the primary do not appear significantly dimmed, we estimate that the secondary (either one or more stars) accounts for up to one-third of the observed total flux in the $B$-band wavelength range. Given the very similar intrinsic $(B-V)$ colour for all early-type stars, a 50 per cent overestimation of the $B$-band flux results in a 50 per cent overestimation of the $V$-band flux, and thus of the bolometric luminosity we have derived in Section 5. Correcting for this factor (0.17 dex in log $L$), the mass of this source decreases to $\sim 60 M_\odot$ and the age reaches the lowest limit covered by the evolutionary models, which predict a zero-age main-sequence (ZAMS) massive star.

We stress that the secondary component for star B may be a line-of-sight object, not necessarily physically related to the O2 star. Besides the colder secondary we have discussed, we underline that even the main object might be a multiple system consisting of similar components. Given the rarity of such stars, studies of binarity for early O-type stars are limited to a few Galactic objects. For example, the O2If prototype, HD 93129A is known to harbour two very similar stars (HD 93129Aa and HD 93129Ab), resolved thanks to HST Fine Guidance Sensors observations (Nelan et al. 2004, 2010). Also Pismis 24-1 [O3.5If + O4III(f)] has been found to consist of at least three similar stars, one of the spectroscopic components being an eclipsing binary (Maíz Apellániz et al. 2007). For our star B, however, it would be hard to assume a multiple system, since the individual components would turn out to be even less luminous than the ZAMS (see Fig. 3), therefore showing parameters inconsistent with the stellar models.

6.2 Evidence for an age spread

Our findings show that there is a spread in the derived ages for the most massive stars. This result is in agreement with our previous study on the age distribution of low-mass PMS stars in LH 95, based on a statistical analysis of the field subtracted optical CMD (Paper II). There we determined an average age of the system of about 4 Myr, with a confirmed age spread compatible with a Gaussian distribution with $\sigma = 1.2$ Myr. In Fig. 6 we present the derived age distribution for the low-mass population, compared to the derived ages of the five massive members analysed here. It should be noted that in this plot we preliminarily consider the ages obtained by neglecting any undetected binaries. From Fig. 6 it appears that three of our sources (stars A, C and D) have an age which is compatible with the low-mass age distribution. Actually, the average age for these stars is exactly 4 Myr. On the other hand, star B appears to be somewhat younger, and star E is significantly away from the average population.

Star E, however, is the faintest source of our sample, and thus has the largest uncertainties; moreover, it is located in a particularly crowded subcluster, as shown in the stellar surface density map of Fig. 7. For this source, stellar confusion may have contributed significantly in biasing the derived parameters of the star. We assess how the presence of unresolved equal-mass binaries, which would introduce the highest bias in the HR diagram position of the stars, affects the observed age differences. We find that star E becomes even older, suggesting derived parameters which are even more peculiar. On the other hand, star A would turn out to be 1.4 Myr older, star D 1.7 Myr younger and the age of star C would not be significantly affected by multiplicity. For these three sources, then, the average age remains compatible with that of the low-mass stars.
The age distribution we derived in Paper II for LH 95 from the analysis of the low-mass population (Gaussian distribution). The arrows, with error bars, indicate the ages and uncertainties of the five massive stars.

![Figure 6](image_url)

**Figure 6.** The age distribution we derived in Paper II for LH 95 from the analysis of the low-mass population (Gaussian distribution). The arrows, with error bars, indicate the ages and uncertainties of the five massive stars.

![Figure 7](image_url)

**Figure 7.** Projected positions of our targets, in relation to the spatial density distribution of low-mass PMS stars in the region, analysed in Paper I. The thick line delimits the central region of the cluster, where the density of PMS stars is above 3 standard deviations from the sparse background. The contours identify regions of higher concentration of PMS stars. In this study we identified three distinct subclusters of such stars (see also section 3.2 in Paper I).

...in the case of unresolved binarity, whereas the measured age spread would increase.

Source B, as previously discussed, is the most interesting case. We find that its age is younger than the others, at $3\sigma$ from the average age of the entire cluster, but still covered by the age distribution derived from the low-mass PMS stars. The uncertainty of this age measurement is relatively small. As we mention in Section 6.1.1, this star appears to be an unresolved composite system, and this implies that the stellar luminosity we have measured (see Table 2) may be overestimated by up to 0.17 dex. This also leads to an even younger age than that we have reported in Section 5, whereas the mass of the source remains quite large ($\sim$60–70 $M_\odot$). In Paper I, we found that LH 95 is a multiple stellar system, consisting of three distinct subclusters, identified in terms of the surface density of the low-mass PMS population in the region (see Fig. 7). Moreover, in Paper II we found that considering the low-mass stars, there is no spatial variation of either average age or age spread throughout the entire region of the cluster, suggesting that the subclusters are probably formed coevally. As seen in Fig. 7, the projected location of source B is very close to the centre of the system, but in a region characterized by a relatively low stellar density, and not associated with any of the three main subclusters of LH 95. Taking these into account, as well as its young age, it seems that source B was formed after the rest of the entire stellar population of LH 95, suggesting that the case of this star is rather peculiar.

We can only hypothesize about the origin of a late-born massive star in LH 95. If source B was born in its current position, its formation may have been triggered by the surrounding population of massive stars. However, it is difficult to justify how a massive clump was prevented from collapsing in the central part of the system for $\sim$3 Myr when massive star formation was taking place in the surrounding region. Also, the low-mass population in the immediate vicinity of source B does not show evidence of a younger age than the rest of the region. Another hypothesis is that source B has not formed in its present position. It is known that 10–25 per cent of the O-type stars are runaways ejected from their birthplace by dynamical interaction (Blauw 1961; Poveda, Ruiz & Allen 1967; Gies & Bolton 1986). Considering a typical ejection velocity of 40–100 km s$^{-1}$, and given the age of source B, of the order of at most $\sim$0.5 Myr, it could have formed about 20–50 pc away from the actual position, i.e. still in the vicinity of the rest of the system. From our spectra, however, we do not measure RV variations between star B and the other members. Also, by visual inspection on the near-infrared (NIR) Two Micron All Sky Survey (2MASS) images, or the mid-IR images obtained with Spitzer Space Telescope, we do not detect the presence of bow shocks, typically produced by runaway stars. Nevertheless, with no proper motion estimates, we are unable to measure the actual velocity of this source, and therefore confirm it as a runaway star. We also stress that our lack of knowledge about the geometry of LH 95 along the line of sight limits our ability to isolate the plausible scenarios responsible for our results concerning star B.

### 7 THE HIGH-MASS STELLAR IMF

In Paper I, we derived the IMF of LH 95, well into the subsolar regime, based on ACS $V$- and $I$-equivalent photometry. We found that the IMF is well approximated by a two-phase power law, with a break point (the ‘knee’ of the IMF) at $\sim 1M_\odot$. In particular, for stellar masses larger than this point, up to $M \sim 15M_\odot$, we measured an IMF slope $\alpha = 3.05$, whereas for stars of subsolar mass the slope decreases to $\alpha = 2.05$. In these units, a Salpeter (1955) IMF corresponds to a slope $\alpha = 2.35$. As mentioned before, the five stars studied here were not included in the analysis of Paper I, due to saturation in the ACS frames. In this section we complete the stellar IMF of LH 95 by adding the results of our analysis on its high-mass end.

Since the subsolar part of the IMF will remain unchanged, we limit our investigation to stars found in Paper I with masses $M > 2M_\odot$. In this mass range the stellar sample includes about 110 members. We utilize the method suggested by Maíz-Apellániz &
The newly estimated IMF slope turns out to be slightly shallower than what we obtained neglecting unresolved companions. This result, compatible with similar of such simulations in the literature (e.g. Sagar & Richtler 1991), shows that unresolved binarity makes the constructed IMF somewhat shallower, but this effect is very small in the high mass range.

7.1 The relation between the most massive star and the cluster mass

The correlation between the mass of the most massive star in a cluster, \( m_{\text{max}} \), and the stellar mass of an entire cluster, \( M_{\text{cl}} \), has been long investigated both through empirical studies and analytical modelling (e.g. Larson 2003; Weidner & Kroupa 2004; Oey & Clarke 2005; Weidner, Kroupa & Bonnell 2010). Its importance is fundamental in several issues, as, for example, it is a critical constrain to the upper mass limit for the formation of a star, and it enables us to investigate whether newborn massive stars in star clusters are randomly drawn from the IMF.

In Paper I we estimated a total stellar mass for LH 95 of \( M_{\text{cl}} \sim 2.4 \times 10^3 \, M_\odot \). Accounting for the most massive stars investigated here, we have \( M_{\text{cl}} \sim 2.5 \times 10^5 \, M_\odot \). Considering also unresolved binaries and a small fraction of diffuse low-mass stars outside the central region, we can constrain \( M_{\text{cl}} \sim 3.0-3.5 \times 10^5 \, M_\odot \). We utilize the model relation \( m_{\text{max}} \) versus \( M_{\text{cl}} \) from Weidner & Kroupa (2004) derived assuming a maximum stellar mass of 150 \( M_\odot \) and the Kroupa (2001) IMF. We stress that the assumed stellar upper mass limit does not affect significantly our analysis, given that the LH 95 cluster is not populated enough to host stellar masses near this limit. Moreover, as we discussed in Paper I, the low-mass population of the region follows the Kroupa IMF once the unresolved binaries are accounted for, and the high-mass IMF derived in our study here also agrees with it. The Weidner & Kroupa (2004) model relation predicts a \( m_{\text{max}} \sim 70 \, M_\odot \) for \( M_{\text{cl}} = 3 \times 10^3 \, M_\odot \) and \( m_{\text{max}} \sim 80 \, M_\odot \) for \( M_{\text{cl}} = 3.5 \times 10^5 \, M_\odot \). These values are in very good agreement with our mass estimate of \( \sim 72 \, M_\odot \) for star B, suggesting that the high-mass population of LH 95 is compatible with a random sampling of stellar masses from its IMF.

On the other hand, our findings are in contrast to the empirical determinations of \( m_{\text{max}} \) in clusters of different mass. As Weidner et al. (2010) point out, carrying out a collective research of cluster masses and maximum stellar mass, there is evidence that the observed \( m_{\text{max}} \) is statistically lower than that predicted across the entire range of \( M_{\text{cl}} \), suggesting the presence of additional mechanisms preventing the formation of the most massive stars in a cluster. These authors show that the relation \( m_{\text{max}} \) versus \( M_{\text{cl}} \) presents a plateau for clusters with \( M_{\text{cl}} \) in the range \( 10^2-4 \times 10^3 \, M_\odot \), where the observed \( m_{\text{max}} \sim 25 \, M_\odot \) is well below the predicted value. Therefore LH 95 follows the empirical Galactic relation only if star B is not a member of the system. The peculiarly younger age for star B seems to support this idea, and we have already hypothesized that this star could be the product of a subsequent star formation event or even a runaway star (see Section 6.2). However, both scenarios suggest that star B was born within the extent of the cluster, and therefore there is little argument against the membership of star B to LH 95.

Finally, we mention that Lamb et al. (2010), by studying the O-type population of sparse clusters of the SMC, found examples of peculiar \( m_{\text{max}}-M_{\text{cl}} \) relations. In particular, they reported the presence of massive stars in clusters with a very small \( M_{\text{cl}} \), in strong disagreement with both the results of Weidner et al. (2010) for the Galactic clusters, and the predictions from the IMF. It is
clear that our understanding of the formation of massive stars is still somewhat incomplete.

8 A B-TYPE EMISSION STAR IN LH 95

As discussed in Section 4, one star in our sample, star A, shows a prominent Balmer emission. Hydrogen emission lines in B-type stars indicate that they are either PMS stars still forming and emitting through accreting circumstellar discs (classified as Herbig Be stars; see Waters & Waelkens 1998, for a review) or evolved B stars with hydrogen emission, classified as classical Be stars (Porter & Rivinius 2003). Classical Be stars are rapidly rotating B-type stars showing a Balmer emission produced in gaseous circumstellar ‘decretion’ discs (Porter & Rivinius 2003). Based on its $T_{\text{eff}}$ and $L_{\text{bol}}$ alone this source could indeed be still in its PMS phase, approaching the MS. However, we exclude this possibility for two reasons. First, the extinction of this star of A $= 0.88$ mag (Section 5) is very low, implying that it is not embedded, and secondly its NIR and mid-IR colours, as we present them later, are much bluer than those of typical Herbig Be stars (Eiroa et al. 2002).

The H$\alpha$ and H$\beta$ profiles from our combined FEROS spectra of star A are shown in Fig. 9. The H$\alpha$ line presents a very broad, nearly symmetric, emission that reaches relative velocities exceeding 400 km s$^{-1}$. At its peak, the net excess is brighter than the local photospheric continuum. The intensity of the H$\beta$ line is weaker in relation to the continuum. Its width is comparable to that of the H$\alpha$ line, but its profile shows two peaks. In order to characterize better the excess emission of star A, we subtract the expected photospheric contribution from its spectrum. In Fig. 9 we also show the approximate shape of the photospheric continuum of the star (blue lines), assuming a TLUSTY (Lanz & Hubeny 2007) model spectrum with $T_{\text{eff}} = 29000$ K, log g = 4.0 and log Z/Z$_{\odot}$ = −0.5. Evidently, these two hydrogen lines are expected to be in absorption from the photosphere. We subtract the photospheric contribution from the observed spectrum and fit the remaining excess with an arbitrary function. Since the emission shows broad wings we find a good match assuming a line profile as the sum of two Gaussian distributions with equal means. The resulting spectrum is also shown for each hydrogen line in Fig. 9 in green colour. While our excess model is possibly oversimplified, we can conclude that the observed double peaked shape of H$\beta$ is not real and can be well reproduced by a broad emission minus a narrower photospheric absorption. Taking the derived emission profiles into account, and given the absence of additional absorption from the circumstellar environment, we classify star A as a classical ‘single line’ Be star, rather than as a shell Be star, i.e. a Be star whose disc is seen edge-on (Rivinius, Štefl & Baade 2006).

Fast stellar rotation is a typical property of Be stars and it is a significant contributor to the generation of the circumstellar medium surrounding these objects. The typical rotation rates of Be stars may be of several hundreds of km s$^{-1}$, a significant fraction of the critical rate. Our spectrum of star A, however, does not show significant line broadening due to stellar rotation. We have quantified the (projected) rotational velocity by considering the synthetic TLUSTY spectrum assumed before, convolved with line spread functions of different values of $v \sin i$. We have then compared the width of the He$\alpha$ with the observed ones. Assuming, for simplicity, rigid rotation, we obtained $v \sin i \sim 60$ km s$^{-1}$. This is a small value for this class of stars and suggests that the stars’ rotation axis is not very inclined from the line of sight. This is compatible with our previous argument that the circumstellar disc is not seen edge-on given the lack of Balmer self-absorption.

Classical Be stars are also known to show an IR excess, commonly interpreted as free-free and free-bound emission of the disc (Gehrz, Hackwell & Jones 1974; Porter & Rivinius 2003; Touhami, Gies & Schaefer 2011). In order to verify this characteristic for star A, we collected NIR and mid-IR photometry for this source. Specifically, we retrieved from the NASA/IPAC Infrared Science Archive IRSA (IRSA) JHK NIR photometry for star A from the 2MASS and mid-IR photometry in 3.6, 4.5, 5.8 and 8.0 $\mu$m from the Infrared Array Camera (IRAC; Fazio et al. 2004) on board the Spitzer Space Telescope (Werner et al. 2004). The resulting spectral energy distribution (SED) is shown in Fig. 10, together with the expected photosphere after adding an extinction of A$_{V} = 0.88$ mag, as estimated in Section 5. The comparison between the SED and the model photosphere confirms the presence of IR excess for this source. We stress that the NIR and mid-IR part of this SED could not be reproduced by any B-type photospheric model even if we would assume a significantly different stellar $T_{\text{eff}}$ than that of star A. The reason lies on the fact that at these wavelengths the spectrum is in the Rayleigh–Jeans regime and so the SED slope does not depend on $T_{\text{eff}}$. Moreover, given the negligible effect of dust extinction at these wavelengths – and the fact that we do measure a very small A$_{V}$ – an inaccurate reddening estimation also cannot justify the observed SED. As a consequence, the observed IR excess of star A is real.

Be stars may also present line variability because of changes in their disc state (McSwain, Huang & Gies 2009). Since our optical spectroscopy for this source was obtained in two epochs (see Table 1), we searched for variations in the Balmer emission by
inspecting the individual exposures from each epoch. Within the ~2 month baseline between the observations, we do not detect any change in the shapes, widths or intensity of neither the H$\alpha$ nor the H$\beta$ emission, as they are shown in Fig. 9. Finally, it is interesting to note that the inferred age of ~4 Myr for this star (see Table 2 and Fig. 3) relies on the assumption that this source is a classical Be star, evolving off the main sequence, and not a forming PMS star.

## 9 CONCLUSIONS

This paper complements our investigation of the stellar OB association LH 95 in the LMC. In our previous studies (Papers I and II), based on deep HST/ACS imaging, we investigated the intermediate- and low-mass PMS population of the system down to 0.4 $M_\odot$. We derived the corresponding IMF, which is found to be compatible with the Kroupa (2001) IMF (Paper I), determined the average cluster age to be ~4 Myr and confirmed an age spread of the order of 2–4 Myr (see also Paper II). We found evidence of spatial variations neither in the IMF nor in the age distribution.

In the present study we focus on the brightest sources in the region which were saturated in our previous HST imaging. We use ground-based high-resolution optical spectroscopy complemented by previous optical photometry to derive the stellar parameters of the five most massive stars, named after the letters A–E, completing thus our census of the LH 95 stellar population across the entire mass spectrum. We perform spectral classification of the sources in terms of the identification of specific spectral lines. We assign masses and ages to these stars, and we discuss the related uncertainties, based on comparison of their HR diagram positions with evolutionary models. We identify an age distribution among the stars, and we use their mass measurements to complete the stellar IMF of LH 95 towards the high-mass regime. We summarize our findings to the following.

(i) The most massive star in the region, star B, is an O2 giant with a mass of ~60–70 $M_\odot$. The case of this star is very interesting. Specifically, it appears to be somewhat younger (<1 Myr) than the rest of the system. In addition, assuming that the established relation between the maximum stellar mass in a cluster and the total mass of the cluster represents the vast majority of clusters, star B is more massive than expected, given the total mass of the stellar system (~$3 \times 10^3$ $M_\odot$). As such, LH 95 appears to be an outlier in this relation. Based on our analysis, we exclude any major bias that might have led us to derive inaccurate stellar parameters for this source.

(ii) The brightest star in the sample, star A, is the second most massive. It is a ~33 $M_\odot$ B0.2 giant with significant hydrogen emission. Specifically, it shows very broad H$\alpha$ and H$\beta$ lines in emission, originating from a gaseous circumstellar disc, as well as clear NIR and mid-IR excess. Considering its low extinction and blue IR colours, we assess that star A is not a Herbig Be PMS star evolving towards the MS, but a classical Be star, evolving away from it.

(iii) The average ages and age spread of the most massive stars are consistent with those previously derived by us for the low-mass PMS populations. Exception to this behaviour is star E, which appears significantly older than the rest of the stars. We assign this peculiarity to the severe crowding by low-mass stars in its immediate surroundings that affects its photometric measurements, and its low brightness, which introduces large uncertainties in our measurements.

(iv) The complete stellar IMF of LH 95, from the most massive stars down to the intermediate-mass regime with $\geq 2$ $M_\odot$, follows a Salpeter slope. Together with the low-mass stars, therefore, this IMF is compatible with a Kroupa IMF.

## ACKNOWLEDGMENTS

We thank Nolan Walborn for his very helpful feedback on spectral classification. The authors acknowledge the Max-Planck Society (MPG) and the Max-Planck Institute for Astronomy (Heidelberg, Germany) for the telescope time. DAG kindly acknowledges financial support by the German Aerospace Centre (DLR) and the German Federal Ministry for Economics and Technology (BMWi) through grant 50 OR 0908, and by the German Research Foundation (DFG) through grant GO 1659/3-1.

## REFERENCES

Baranne A. et al., 1996, A&AS, 119, 373
Bessell M. S., Castelli F., Plez B., 1998, A&A, 333, 231
Bica E. L. D., Schmitt H. R., 1995, ApJS, 101, 41
Bica E. L. D., Schmitt H. R., Dutra C. M., Oliveira H. L., 1999, AJ, 117, 238
Blauw A., 1961, Bull. Astron. Inst. Netherlands, 15, 265
Cardelli J. A., Clayton G. C., Mathis J. S., 1989, ApJ, 345, 245
Da Rio N., Gouliermis D. A., Henning T., 2009, ApJ, 696, 528 (Paper I)
Da Rio N., Gouliermis D. A., Gennaro M., 2010, ApJ, 723, 166 (Paper II)
Davies R. D., Elliott K. H., Meaburn J., 1976, Mem. R. Astron. Soc., 81, 89
Eiroa C. et al., 2002, A&A, 384, 1038
Evans C. J. et al., 2010, ApJ, 715, L74
Fazio G. G. et al., 2004, ApJS, 154, 10
Gehrz R. D., Hackwell J. A., Jones T. W., 1974, ApJ, 191, 675
Gies D. R., Bolton C. T., 1986, ApJS, 61, 419
Girardi L., Bertelli G., Bressan A., Chiosi C., Groenewegen M. A. T., Marigo P., Salasnich B., Weiss A., 2002, A&A, 391, 195
Gordon K. D., Clayton G. C., Misselt K. A., Landolt A. U., Wolff M. J., 2003, ApJ, 594, 279

© 2012 The Authors, MNRAS 422, 3356–3369
Monthly Notices of the Royal Astronomical Society © 2012 RAS
