Blue massive stars in NGC 55: a first quantitaive study

N. Castro, A. Herrero, M. Garcia, C. Trundle, F. Bresolin, W. Gieren, G. Pietrzynski and R.-P. Kudritzki, and R. Demarco

Abstract We present the first census of blue massive stars in NGC 55, a galaxy of the Sculptor group at 1.94 Mpc. This study is based on optical low–resolution spectra of approximately 200 objects taken with VLT–FORS2. We have performed the spectral classification of these objects.

The estimated stellar radial velocities show general agreement with the existing H I rotational velocity data. A first qualitative study of the stellar metallicity suggests that its global distribution over NGC 55 is close to that of the LMC, as derived from previous studies of H II regions. We have also determined the stellar parameters of one star showing that the resolution and the quality of the spectra are reliable to perform a quantitative analysis.

1 Introduction

Massive stars are scarce compared with the rest of stars. For each $\sim 20\ M_{\odot}$ star we can find about 10^5 stars similar to the Sun. Their high mass cause a

N. Castro · A. Herrero · M. Garcia
Instituto de Astrofísica de Canarias, C/ Vía Láctea s/n, E-38200, Tenerife, Spain. e-mail: norberto@iac.es

C. Trundle
Astronomy Research Centre, Department of Physics & Astronomy. School of Mathematics & Physics. The Queen's University of Belfast, Belfast, UK.

F. Bresolin · R.-P. Kudritzki
Institute of Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822, USA.

W. Gieren · G. Pietrzynski
Departamento de Física, Astronomy Group, Universidad de Concepción, Casilla 160-C, Concepción, Chile.

R. Demarco
Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, USA.

huge internal activity leading to a high radiation pressure that sweeps away the outer layers to the interstellar medium ($10^{-11} - 10^{-4}$ $M_{\odot}/year$). The high mass also makes that these stars to live fast and die "young" ($10^{6} - 10^{7}$ years) as a supernova explosion. In spite of their short existence, the role of these stars in the dynamical and chemical evolution of galaxies is remarkable due to the injection of momentum and material during their entire life. Additionally, thanks to their short lives we can use massive stars as a tool to determine the present chemical composition of the host galaxies since the abundances measured in their atmosphere are almost no contaminated with processed material and represent the medium from which the star was born. These objects can also be used as a distant candles (see [14]).

Nonetheless, one of the most relevant properties is their high luminosity. This, together with new generation $8 - 10$ m class telescopes, has renewed the interest in the exploration of massive stars in nearby galaxies, even beyond the Local Group. Going outside of the Milky Way (MW) gives us the possibility of understanding the formation and evolution of these stars in environments with different metallicity. Besides, we can study the chemical composition of the whole projected galaxy. However, it has several implicit problems: a lower signal-to-noise ratio (S/N), binary unresolved systems or a hard nebular subtraction. Nevertheless, the last generation of instruments allows us to cope with these issues. Out of the Galaxy, the Magellanic Clouds are the most targeted due to their proximity [12] but there have been additional works on other galaxies of the Local Group include: M 31 [21], M 33 [23], NGC 6822 [24], NGC 3109 [8], WLM [2] or IC 1613 [3]. Even out of the Local Group in NGC 300 [14].

We now extend the study to NGC 55. This galaxy is located in the Sculptor group at 1.94 Mpc [10], close enough to allow quantitative spectroscopic analyses of bright blue stars. Its large inclination angle ($\sim$80°, [11]) makes its morphological classification difficult. Some authors argue that NGC 55 is a Magellanic irregular (for instance [5]), however we adopt a SB(s)m classification [6].

2 Data

Targets were selected from existing V- and I-band photometry obtained as part of the ongoing Araucaria Cepheid search project [18]. Magnitude (V) and colour ($V - I$) were the main criteria for candidate selection. The final list of candidates was built by careful examination of the images to reject objects with nearby companions and to avoid overlap with H II regions.

We obtained spectra for $\sim$200 objects with FORS2 at the Very Large Telescope, in the MXU mode. The spectra were taken with the 600B grism which, at that time, provided the highest resolving power for this study ($\lambda/\delta\lambda = 780$) in the wavelength range of interest ($3100 - 6210$Å).

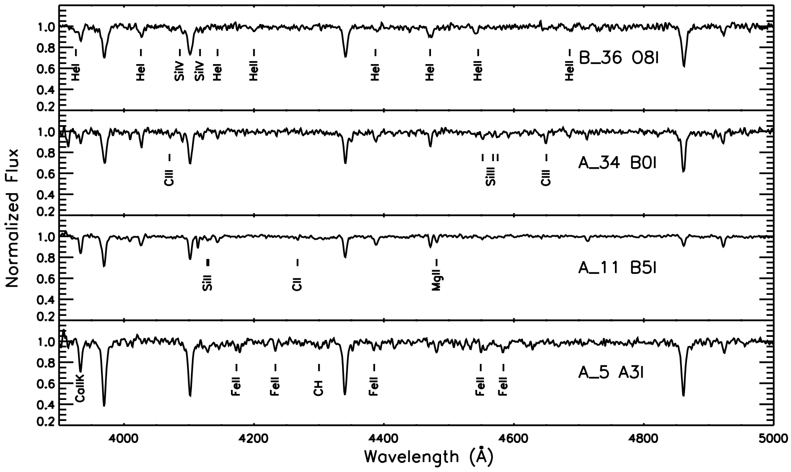

Fig. 1 Observed spectra of early supergiants in NGC 55. The hydrogen lines, helium and metallic transitions (marked in the plot) are clearly seen.

The spectra were reduced with the pipeline developed by Demarco et al. [7], optimised for FORS2 data and upgraded for this work. Sky subtraction was a laborious task due to nebular emission. Nevertheless, in the vast majority of our targets the nebular lines do not compromise our analysis.

3 Spectral Classification

The morphological analysis of stellar spectra is a crucial first step in studying the population of massive stars since it provides clues about the stellar parameters of the stars. The system developed by Morgan et al. [17], together with subsequent refinements [25], is the basis for the classification of Galactic stars. These criteria are metallicity dependent. Therefore we also used objects from the Magellanic Clouds as standards.

Existing NGC 55 H II regions studies indicate that its metallicity is close to Large Magellanic Cloud (LMC) the [22]. We have performed the spectral classification by visual comparison with templates from LMC stars. The luminosity class was determined following [25] for O-type stars and using the width of Balmer lines for B- and A-stars [1].

We have provided detailed classifications for 204 spectra, out of which 164 stars seem to belong to NGC 55 and have spectral types earlier than F0. We have found a total of 14 O-type , 75 B-type and 68 A-type stars. There is also a group of 7 NGC 55 blue stars that have been classified like WR and LBV candidates. Some examples are shown in Fig. 1. The complete catalogue is available in Castro et al. [4].

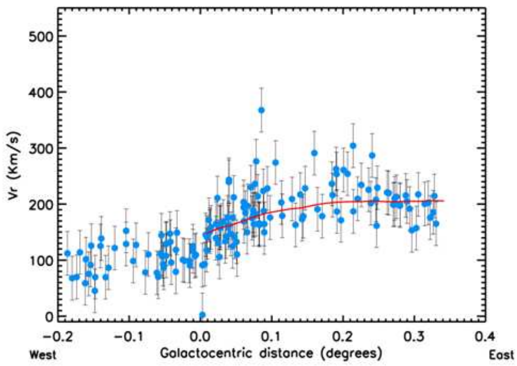

Fig. 2 Stellar radial velocities of NGC 55 blue stars as a function of the projected galactocentric distance. The galaxy's rotational curve derived from H I regions [19] (red line) is included for comparison.

4 Radial Velocity

Radial velocities were determined from the Doppler wavelength shift of strong absorption lines. The resulting radial velocities are plotted in Fig. 2 as a function of the projected galactocentric distance. We have also plotted the rotation curve derived from H I observations [19]. Figure 2 shows how the stellar population traces the rotation of the galaxy, even in its outer parts, as found in NGC 3109 [8]. We obtain a systematic velocity of $\sim$120 km s^{-1}, very similar to the 129 km s^{-1} obtained so far [13].

One of the objects shows a low radial velocity compared with the other stars and its spectrum exhibits no hint as to the reason for its small radial velocity. It may be a halo Galactic star. However, this would be completely inconsistent with its classification as a supergiant since it would be brighter. Therefore, we cannot exclude the possibilities that either a supernova explosion or binarity can be the cause of its peculiar radial velocity. The other object with a larger velocity than the rest is actually a cluster.

5 Metallicity Estimate

We have qualitatively derived the metal content of NGC 55 stars. A subset of spectral lines (silicon and magnesium) were compared with objects of similar spectral type from the MW [16], LMC [9] and SMC [15]. The analysis was performed on a set of supergiant stars (B0-A0).

We find that the average metal content of NGC 55 supergiants is similar to those of the LMC. At first glance the spatial distribution (see Fig. 3) does not show any obvious variation across the galaxy. However a more detailed inspection reveals a slight variation. At a projected galactocentric distance of 0.15 degrees and greater the population of stars with lower metallicity increases compared to the central population.

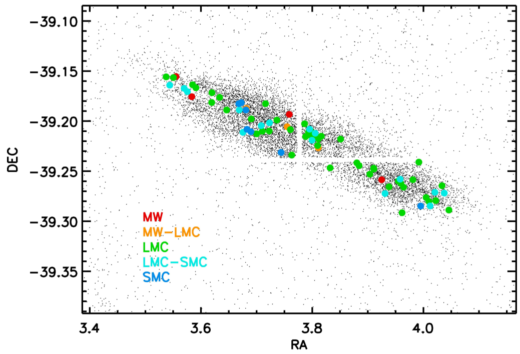

Fig. 3 Metallicity distribution of B0-A0 supergiants in NGC 55, the different colours indicate their metallicity (as shown in the plot). The average metallicity is close to the LMC.

The high inclination angle of NGC 55 complicates our study. We cannot ensure that stars apparently close to the centre are indeed in the disk of the galaxy and not in an outer layer but in the line of sight towards the centre. Nevertheless, the indirect evidence of a radial gradient found here cannot be considered significant until we perform a quantitative analysis.

6 Quantitative Analysis

Modelling the atmospheres of these stars is complex. Quantitative studies require a state-of-the-art atmosphere model that works in non-local thermodynamical equilibrium (n-LTE) with an accurate treatment of the wind in a spherically extended atmosphere. We used the code FASTWIND [20] and a detailed atomic model of particular elements to derived their abundances.

We have derived the stellar parameters and abundances of a B2.5 I star on NGC 55. The best fit models and derived parameters are shown in Fig. 4.

7 Next Step

The long-term goal of our project is to obtain the physical parameters and abundances of a larger sample of blue massive stars in NGC 55. As an initial step, we have presented the first census of blue massive stars in NGC 55 with spectral classification for 164 have types earlier than F0 (for more details see Castro et al. [4]).

The first quantitative test has shown that the quality of the spectral sample is adequate for determination stellar parameters and abundances. By studying a larger sample we will provide important constraints for massive stars evolution in different metallicity environments.

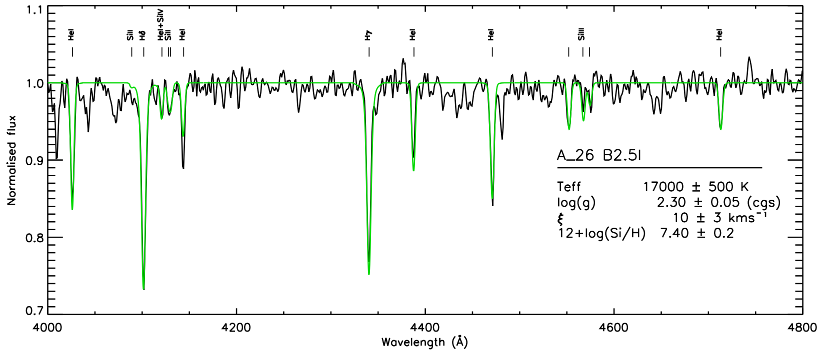

Fig. 4 Quantitative analysis of A_26 a B2.5I in NGC 55. The figure also shows the stellar parameters derived for this star: effective temperature (Teff), gravity (log(g)), microturbulence (ξ) and silicon abundance (log(Si/H)). The S/N and the resolution are suitable to perform this study.

Acknowledgements This work has been supported by the Spanish *Ministerio de Educación y Ciencia*, grant number AYA2004-08271-C02-012 and AYA2007-67456-C02-01.

References

1. Azzopardi, M.: A&AS **69**, 421–438 (1987)
2. Bresolin, F., Pietrzyński, G., Urbaneja, M.A., et al.: ApJ **648**, 1007–1019 (2006)
3. Bresolin, F., Urbaneja, M.A., Gieren, W., et al.: ApJ **671**, 2028–2039 (2007)
4. Castro, N., Herrero, A., Garcia, M., et al.: A&A **485**, 41–50 (2008)
5. Davidge, T.J.: ApJ **622**, 279–293 (2005)
6. de Vaucouleurs, G.: ApJ **133**, 405–+ (1961)
7. Demarco, R., Rosati, P., Lidman, C., et al.: A&A **432**, 381–394 (2005)
8. Evans, C.J., Bresolin, F., Urbaneja, M.A., et al.: ApJ **659**, 1198–1211 (2007)
9. Evans, C.J., Lennon, D.J., Smartt, S.J., et al.: A&A **456**, 623–638 (2006)
10. Gieren, W., Pietrzynski, G., Soszynski, I., et al.: ApJ **672**, 266–000 (2008)
11. Hummel, E., Dettmar, R.J., Wielebinski, R.: A&A **166**, 97–106 (1986)
12. Hunter, I., Dufton, P.L., Smartt, S.J., et al.: A&A **466**, 277–300 (2007)
13. Koribalski, B.S., Staveley-Smith, L., Kilborn, V.A., et al.: AJ **128**, 16–46 (2004)
14. Kudritzki, R.P., Urbaneja, M.A., Bresolin, F., et al.: ApJ **681**, 269–289 (2008)
15. Lennon, D.J.: A&A **317**, 871–882 (1997)
16. Lennon, D.J., Dufton, P.L., Fitzsimmons, A.: A&AS **94**, 569–586 (1992)
17. Morgan, W.W., Keenan, P.C., Kellman, E.: (1943)
18. Pietrzyński, G., Gieren, W., Soszyński, I., et al.: AJ **132**, 2556–2565 (2006)
19. Puche, D., Carignan, C., Wainscoat, R.J.: AJ **101**, 447–455 (1991)
20. Puls, J., Urbaneja, M.A., Venero, R., et al.: A&A **435**, 669–698 (2005)
21. Trundle, C., Dufton, P.L., Lennon, D.J., et al.: A&A **395**, 519–533 (2002)
22. Tüllmann, R., Rosa, M.R., Elwert, T., et al.: A&A **412**, 69–80 (2003)
23. Urbaneja, M.A., Herrero, A., Kudritzki, R.P., et al.: ApJ **635**, 311–335 (2005)
24. Venn, K.A., Lennon, D.J., Kaufer, A., et al.: ApJ **547**, 765–776 (2001)
25. Walborn, N.R., Fitzpatrick, E.L.: PASP **102**, 379–411 (1990)