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Letter to the Editor

VLT FORS spectra of blue supergiants in the Local Group galaxy NGC 6822

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Abstract. Half hour exposures using the ESO VLT/FORS1 combination at Parañal in Chile have allowed us to obtain spectra for three B supergiants in the dwarf irregular galaxy NGC 6822. The spectra have been analysed using non-LTE techniques and temperatures, gravities, helium content and abundances have been obtained. Overall the metallicity of NGC 6822 is found to lie between that of the LMC and of the SMC, in agreement with previous observations of H II regions and in contrast to the earlier findings of Massey et al. (1995). The analysis of H_α yields estimates of the mass-loss rates and wind momenta. These results demonstrate that significantly longer exposures with the same instruments will allow us to perform quantitative spectroscopy of blue supergiants in galaxies far beyond the Local Group.

Key words: atomic data – line: formation – stars: Hertzsprung–Russel (HR) and C-M diagrams – stars: early-type – stars: supergiants

1. Introduction

The current generation of 8 m telescopes are bringing exciting new opportunities for the investigation of individual stars in distant galaxies. The Very Large Telescope (VLT) together with the FORS spectrograph are a combination that should allow optical spectra to be obtained for stars in galaxies as far as the Virgo and Fornax clusters. This has implications for investigations of the properties of the stars themselves, but also their host galaxies in terms of star formation, dynamical and chemical evolution. The use of these spectra and the Wind Momentum-Luminosity-Relationship (WLR) (Kudritzki et al., 1999) will make it possible to determine accurate distances to these galaxies and hence will enable us to make independent estimates of cosmological quantities, and in particular, the Hubble constant. The WLR itself has a metallicity dependence which makes it essential that we are able to obtain metallicities for the objects under consideration. This then is the main goal of the paper presented here. We wish to show, using NGC 6822 as an example, that spectra, obtained using the VLT/FORS1 instruments, can be analysed to provide the abundances needed and allow a determination of stellar wind momenta.

On the other hand, NGC 6822, a dwarf irregular member of the Local Group is in itself an object of interest. With a distance modulus of 23.49 (Gallart et al. 1996) it has been the subject of a number of studies looking at its morphology (e.g. Hutchings et al., 1999) and hot star content. The latter work has been summarized in the papers of Wilson (1992) and Massey et al. (1995). NGC 6822 has long been known to have a lower metallicity than the solar neighborhood of our own Galaxy and estimates based on studies of H II regions have suggested that a value intermediate between that of the Galaxy and the SMC is appropriate (Pagel et al., 1980; Elias and Frogel, 1985). The logarithmic O/H ratios (on the usual scale with $\log$ H=12) are 8.2 for NGC6822 and 8.0 for the SMC according to Pagel et al. (1978), with the solar neighborhood value being approximately 8.70 (Meyer et al. 1998, Gies & Lambert 1992). Massey et al. (1995) suggested that NGC6822's metallicity could be even lower than that of the SMC on the basis of intermediate dispersion spectra of B-type supergiants obtained with the CTIO 4m telescope. However this was a qualitative estimate obtained by deriving the spectral types of the B-stars and a visual comparison of line strengths with similar SMC stars. Thus it is of some interest to have further analyses of stars of NGC 6822 to clarify the point. The B-type supergiants are ideal for this purpose as they have formed recently out of the interstellar material, are not too evolved and consequently their photospheres are expected to mirror the metallicity of the surrounding material. We note

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Table 1.

Slit	Name	RA 2000	Dec 2000	V	Sp. T. this work	Sp. T. previous	$T_{\rm eff}$ 10^3K	$\log g$ cgs	R $R_\odot$
5	ob6-16	19 44 49.41	−14 44 03.9	18.11	B0 Ia	O9 II	28 ± 2	3.0 ± 0.2	27.4
6	ob11-8	19 45 00.41	−14 44 34.6	18.41	B2 Ia	Early B	23 ± 2	2.9 ± 0.2	27.8
19	slit 19	19 44 55.20	−14 49 30.4	17.73	B9 Ia	B1 Ia	13 ± 1	1.8 ± 0.1	66.2

that Foo et al. (1999) have very recently performed an abundance analysis of an A supergiant in NGC 6822. They found that their star possessed a metallicity midway between that of the SMC and the LMC, in agreement with the earlier work of Pagel et al. (1980) and Skillman et al.(1989).

Thus our aims are twofold: we wish to show that with VLT/FORS we are in a position to perform quantitative spectroscopy of stars in galaxies far beyond the Local Group and secondly, we wish to give some input to the question of the metallicity of NGC 6822 itself.

2. Observations and analysis

We have obtained spectra for a number of B supergiants in NGC 6822, of which three will be discussed here. Further details for the stars are summarized in Table 1 where the names have been taken from the paper of Massey et al. (1995). Also given are the spectral classifications according to these authors. The observations were made on two nights using the VLT UT1 together with FORS1 in MOS mode during Commissioning 1 at the beginning of October 1998. Two grisms covering the blue (330–700nm) and red (435–850nm) wavelength regions were used. The slit widths were 1 second of arc and the slit positions are also to be found in Table 1, while exposure times of 1800s for both spectral ranges were deemed adequate. Lastly the seeing was 0.8 second of arc. At this phase of the FORS commissioning the MOS target acquisition was still not perfect and the signal in our data suffers from fairly substantial slit losses. However even these single 30 minute exposures are of adequate quality that they allow us to estimate the stellar metallicities and extrapolate the performance of FORS when observing blue supergiants in galaxies beyond the Local Group.

In addition, the flat fields are partially saturated introducing extra noise. Despite these complications the data remain useful for a first spectroscopic investigation.

As a first step to obtain information about stellar parameters and metallicity we have determined spectral types following the abundance independent criteria of Lennon (1997). The results are given in Table 1 and comparisons with galactic and SMC objects of similar spectral type are displayed in Figs. 1–3. In making this comparison we have convolved the galactic and SMC spectra with an instrumental profile with a FWHM of 4 Å to simulate the resolution of the FORS1 spectrograph. Even at this stage the low metallicity of NGC 6822 is apparent. We also note that the spectra correspond well to the SMC objects indicating that the abundances in the two galaxies are similar.

Starting from the spectral types we were then able to obtain temperatures, $\log g$ and metallicity from NLTE model atmosphere spectroscopy using the same methods as McErlean et al. (1998). The model atmospheres are H-He structures calculated using the TLUSTY program of Hubeny and Lanz (1995). The model atoms correspond to those of McErlean et al. except for oxygen and magnesium where we were able to use the results of Przybilla et al. (1999a, 1999b). Fe II was treated in LTE following Becker and Butler (1999). The results are tabulated in Table 1 and plots are shown in Fig. 4. (Although not included in the tables, a microturbulence is estimated to be $7{\pm}2\,{\rm kms}^{-1}$ for all the objects). We estimate the overall metallicity of each

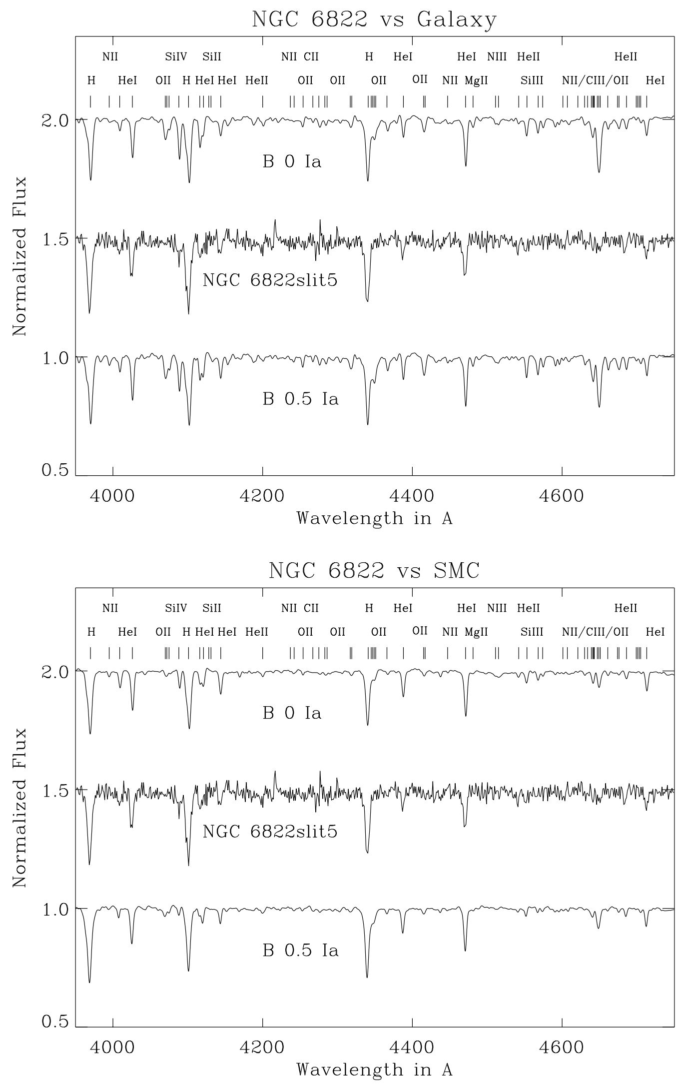

Fig. 1. Comparison of the NGC 6822 object ob6-16 with Galactic and SMC stars of similar spectral type

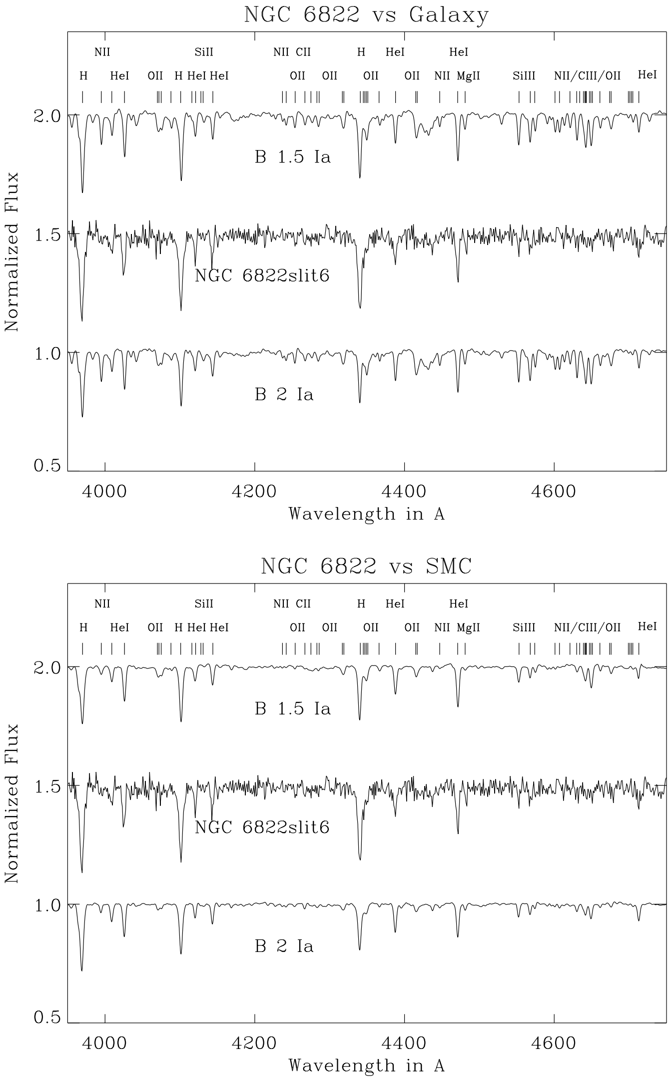

Fig. 2. Comparison of the NGC 6822 object ob11-8 with Galactic and SMC stars of similar spectral type

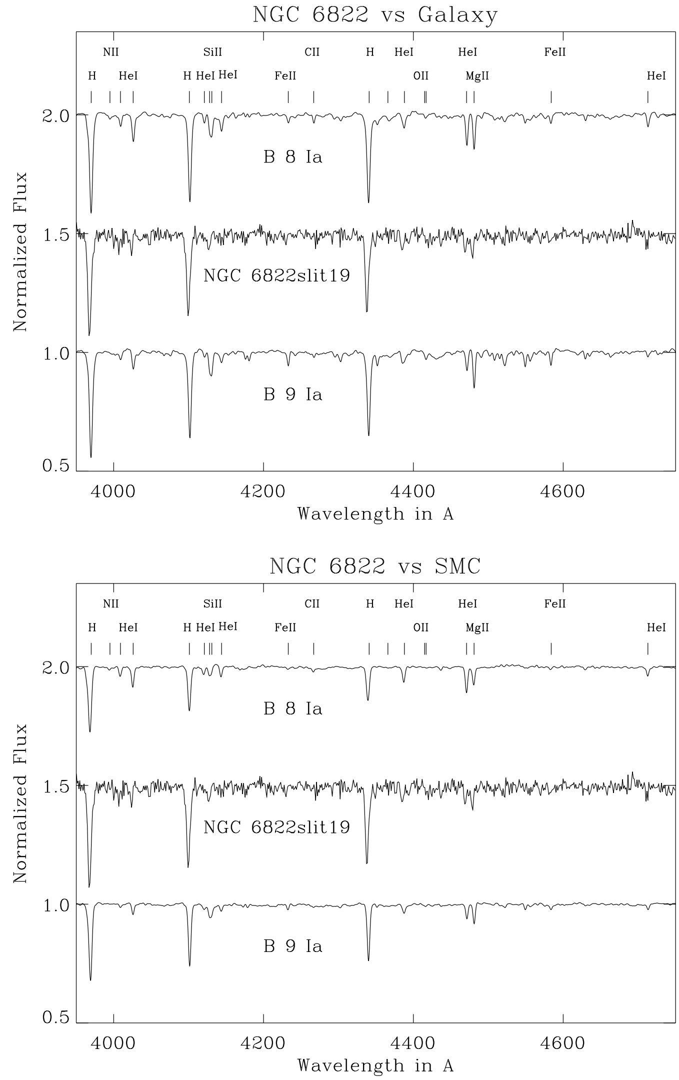

Fig. 3. Comparison of the NGC 6822 object slit 19 with Galactic and SMC stars of similar spectral type

of the stars to be -0.5 ± 0.2 dex relative to the sun (solar values from Arnaud and Rothenflug, 1985).

With $T_{\rm eff}$ and $\log g$ obtained from the analysis and the distance modulus we can use photometry (Massey et al. 1995 and references therein) to determine the reddening (E(B-V) = 0.35 mag), and stellar radii (Table 1). Hydrodynamic model atmospheres (Santolaya-Rey et al. 1997) are then applied to estimate mass-loss rates from the observed H_α line profiles using the same technique as Kudritzki et al. (1999). The corresponding fits are shown in Fig. 5; Because of the low metallicity the winds of these luminous stars are extremely weak and all H_α profiles are in absorption. As explained by Kudritzki et al., this still allows a determination of the mass-loss rates, however with a larger uncertainty. In addition, in such a case the terminal velocity cannot be determined directly from H_α (we would need UV spectra to be taken with HST) and has to be estimated according to the spectral type. We adopt 1000 $\rm kms^{-1}$ for the two early B Ia-objects (slit5 and slit6) and 300 $\rm kms^{-1}$ for slit19 which is almost an early A-supergiant (see Kudritzki et al.). The mass-loss rates obtained in this way are 2×10^{-7}, 1×10^{-7} and 5×10^{-8} $M_\odot$/yr for slit5, 6 and 19, respectively. The corresponding wind momenta are plotted in Fig. 6 (the estimated uncertainties are ±0.3 dex). Compared with solar neighborhood stars in the Milky Way, the wind momenta in NGC 6822 are significantly lower. This is certainly a consequence of the substantially lower metallicity. However, a difference of 1 dex in wind momentum relative to the Galaxy is more than one would expect from stellar wind theory (see Kudritzki, 1998). Spectroscopic work on B-supergiants in the SMC, presently under way in our group, and more objects in NGC 6822 will allow us to disentangle whether this is a problem with the theory. Further we need to determine the iron abundance in NGC 6822, as this element with it's strong UV opacity plays a key role in driving the stellar outflow; this is best achieved by observing A-type supergiants at relatively high spectral resolution (e.g. with UVES).

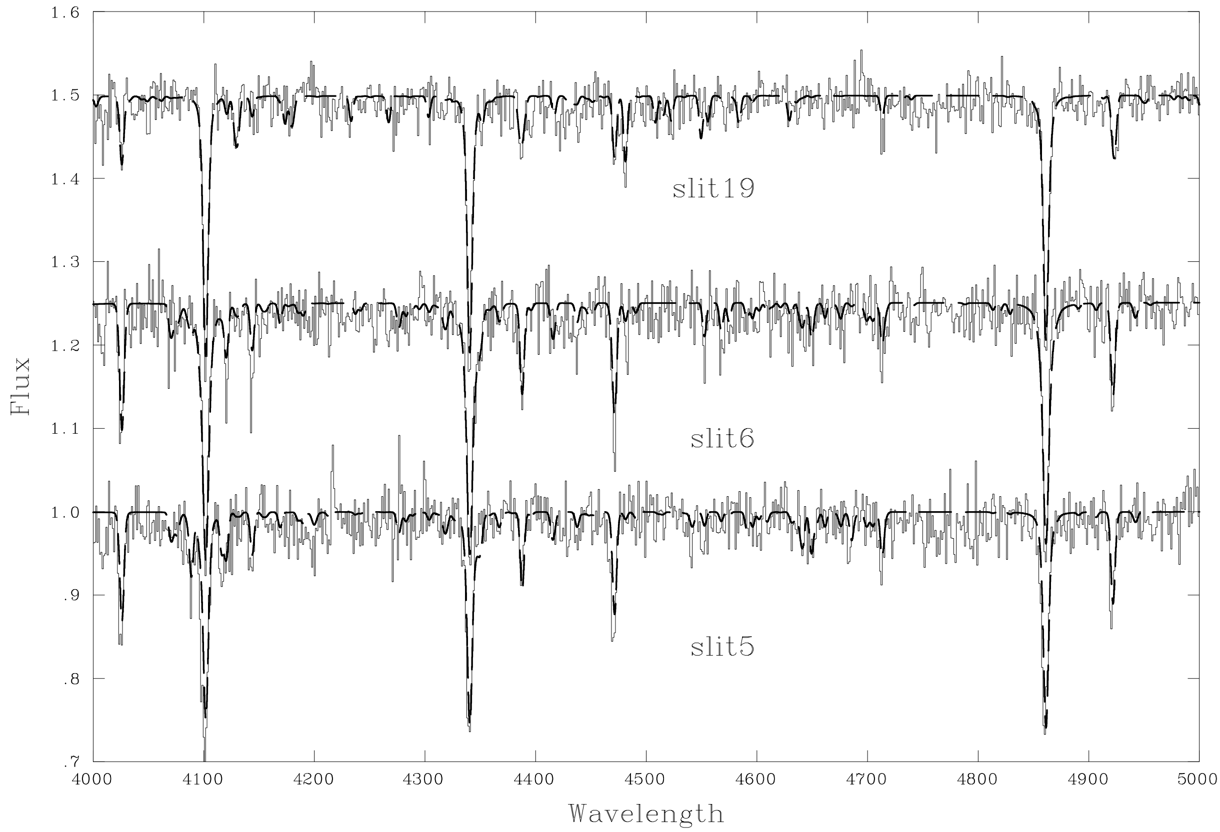

Fig. 4. Comparison of observed spectra of NGC 6822 (full line) and theoretical results for 0.3 times (dotted) solar.

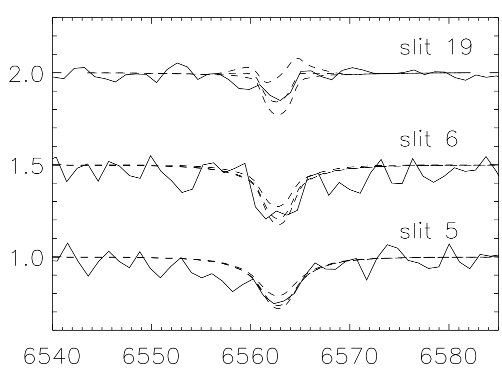

Fig. 5. Fit of the observed H_α profiles by means of hydrodynamic NLTE model atmospheres with winds (see text). For each star three profiles differing by 0.3 dex in the adopted value of the mass-loss rate are shown.

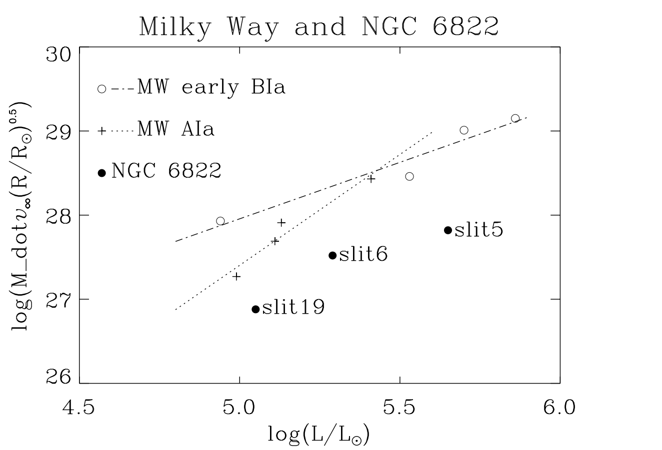

Fig. 6. Stellar wind momenta for blue supergiants in the Milky Way and for the three objects in NGC 6822 as function of luminosity. The data for the Milky Way objects (including the regression curves) are taken from Kudritzki et al. (1999).

3. Discussion

This work demonstrates that by using FORS 1 on the VLT it is possible to derive metallicities, temperatures and gravities for B-type supergiants in a local group dwarf irregular galaxy, at least for the earlier spectral types.

The overall metallicity of NGC 6822 from our small sample has been shown to lie between that of the LMC and the SMC with an estimated value of -0.5 ± 0.2 dex relative to the sun. This is in contradiction to the results of Massey et al. (1995) who suggested an under-abundance relative to the SMC. A possible explanation is indicated in Table 1 where the spectral types derived here following the work of Lennon (1997) are compared with the earlier work. There are large differences between the two studies which in turn imply different temperatures and different abundance estimates. Lennon (1997) showed that special criteria are needed for the spectral classification of B-supergiants at low metallicity. In contrast, the Massey et al. classification has used ratios of metal lines to those of hydrogen and helium, but on the scale of nearby Galactic spectral type 'standards'. It is likely that the intrinsically lower abundance of NGC6822 will affect these ratios significantly leading to possible errors in the luminosity and spectral type classification.

More importantly we estimate that with full night exposures of 10 hours (and improved MOS target acquisition as is now possible with FORS) we can perform spectroscopy for similar objects at $m_v = 22$ mag thus reaching stars in galaxies far beyond the Local Group (note that the absolute magnitudes of the brightest blue supergiants are about $M_v = -9$ mag, see Kudritzki (1998). In this way, it will be possible to study blue supergiants in the WFPCII fields of the HST distance scale Key-project to provide metallicities for the Cepheid period-luminosity relationship and for the independent WLR distance determinations which will use H_α line profile fits for the determination of wind momenta. Moreover, abundance gradients in galaxies can be obtained yielding information about the chemical evolution of galaxies complementary to the investigation of H II-regions.

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