Extragalactic stellar astronomy with the brightest stars in the universe

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Abstract

Supergiants are objects in transition from the blue to the red (and vice versa) in the uppermost HRD. They are the intrinsically brightest ‘normal’ stars at visual light with absolute visual magnitudes up to \(M_V \sim -9\). They are ideal to study young stellar populations in galaxies beyond the Local Group to determine chemical composition and evolution, interstellar extinction, reddening laws and distances. We discuss the most recent results on the quantitative spectral analysis of such objects in galaxies beyond the Local Group based on medium and low-resolution spectra obtained with the ESO VLT and Keck. We describe the analysis method including the determination of metallicity and metallicity gradients. A new method to measure extragalactic distances accurately based on stellar gravities and effective temperatures is presented, the flux-weighted gravity—luminosity relationship (FGLR). The FGLR is a purely spectroscopic method that overcomes the uncertainties, introduced by interstellar extinction and variations of metallicity, which plague all methods of photometric stellar distance determination. We discuss the perspectives of future work using the giant ground-based telescopes of the next generation such as the TMT, the GMT and the E-ELT.

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1. Introduction

It has long been the dream of stellar astronomers to study individual stellar objects in distant galaxies to obtain detailed spectroscopic information about the history of star formation and the chemodynamical evolution of galaxies, and to determine accurate distances based on the determination of stellar parameters and interstellar reddening and extinction. At first glance, one might think that the most massive and, therefore, most luminous stars with masses higher than \(50M_\odot\) are ideal for this purpose. However, because of their very strong stellar winds and mass loss, these objects keep very hot atmospheric temperatures throughout their life and, thus, waste most of their precious photons in the extreme ultraviolet region. As we all know, most of these UV photons are killed by dust absorption in the star forming regions, where these stars are born, and the few which make it to the Earth can only be observed with tiny UV telescopes in space such as the HST or FUSE and are not accessible to the giant telescopes on the ground.

Thus, one learns quickly that the most promising objects for such studies are massive stars in a mass range between 15 and \(40M_\odot\) in the short-lived evolutionary phase, when they leave the hydrogen main-sequence and cross the HRD in a few thousand years as blue supergiants of the late B and early A spectral types. Because of the strongly reduced absolute value of bolometric correction when evolving towards smaller temperature, these objects increase their brightness in visual light and become the optically brightest ‘normal’ stars in the universe with absolute visual magnitudes up to \(M_V \sim -9.5\) rivalling the integrated light brightness of globular clusters and dwarf spheroidal galaxies. These are the ideal stellar objects from which to obtain accurate quantitative information about galaxies.

2. Studies in the Milky Way and Local Group

There has been a long history of quantitative spectroscopic studies of these extreme objects. In a pioneering and comprehensive paper on Deneb Groth (1961) was the first to...
obtain stellar parameters and detailed chemical compositions. This work was continued by Wolf (1971, 1972, 1973), in studies of A supergiants in the Milky Way and the Magellanic clouds. Kudritzki (1973) using newly developed NLTE model atmospheres found that at the low gravities and the correspondingly low electron densities of these objects, effects of departures from LTE can become extremely important. With strongly improved model atmospheres Venn (1995a, 1995b) and Aufdenberg et al (2002) continued these studies on the Milky Way. Most recently, Przybilla et al (2006) and Schiller and Przybilla (2008) used very detailed NLTE line formation calculations including tens of thousands of lines in NLTE (see also Przybilla et al 2000; Przybilla et al 2001a, b, Przybilla and Butler 2001) to determine stellar parameters and abundances with hitherto unknown precision ($T_{\text{eff}}$ to $\lesssim 2\%$, log $g$ to $\sim 0.05$ dex, individual metal abundances to $\sim 0.05$ dex). At the same time, utilizing the power of the new 8–10 m class telescopes, high-resolution studies of A supergiants in many Local Group galaxies were carried out by Venn (1999) (SMC), McCarthy et al (1995) (M33), McCarthy et al (1997) (M31), Venn et al (2000) (M31), Venn et al (2001) (NGC 6822), Venn et al (2003) (WLM) and Kaufer et al (2004) (Sextans A), yielding invaluable information about the stellar chemical composition in these galaxies. In the field of research of massive stars, these studies have so far provided the most accurate and most comprehensive information about their chemical composition, and have been used to constrain the stellar evolution and the chemical evolution of their host galaxies.

3. The challenging step beyond the Local Group

The concept to go beyond the Local Group and to study A supergiants by means of quantitative spectroscopy in galaxies out to the Virgo cluster was first presented by Kudritzki (1995, 1998). Following up on this idea, Bresolin et al (2001) and Bresolin et al (2002) used the VLT and FORS at 5 Å resolution for a first investigation of blue supergiants in NGC 3621 (6.7 Mpc) and NGC 300 (1.9 Mpc). They were able to demonstrate that for these distances and at this resolution spectra of sufficient S/N can be obtained allowing for the quantitative determination of stellar parameters and metallicities. Kudritzki et al (2003) extended this work and showed that stellar gravities and temperatures determined from the spectral analysis can be used to determine distances to galaxies by using the correlation between absolute bolometric magnitude and flux-weighted gravity $g_{\star} = g / T_{\text{eff}}^{3}$ flux-weighted gravity–luminosity relationship (FGLR). However, while these were encouraging steps toward the use of A supergiants as quantitative diagnostic tools of galaxies beyond the Local Group, the work presented in these papers still had a fundamental deficiency. At the low resolution of 5 Å, it is not possible to use ionization equilibria for the determination of $T_{\text{eff}}$ in the same way as in the high-resolution work mentioned in the previous paragraph. Instead, spectral types were determined and a simple spectral type—temperature relationship as obtained for the Milky Way was used to determine effective temperatures and then gravities and metallicities. Since the spectral type—$T_{\text{eff}}$ relationship must depend on metallicity (and also gravities), the method becomes inconsistent as soon as the metallicity is significantly different from the solar (or the gravities are larger than for the luminosity class Ia) and may lead to inaccurate stellar parameters. As shown by Evans and Howarth (2003), the uncertainties introduced in this way could be significant and would make it impossible to use the FGLR for distance determinations. In addition, the metallicities derived might be unreliable. This posed a serious problem for the low-resolution study of A supergiants in distant galaxies.

This problem was overcome only very recently by Kudritzki et al (2008) (hereafter KUBPGP), who provided the first self-consistent determination of stellar parameters and metallicities for A supergiants in galaxies beyond the Local Group based on the detailed quantitative model atmosphere analysis of low-resolution spectra. They applied their new method to 24 supergiants of spectral types B8 to A5 in the Sculptor Group spiral galaxy NGC 300 (at a distance of 1.9 Mpc) and obtained the temperatures, gravities, metallicities, radii, luminosities and masses. The spectroscopic observations were obtained with FORS1 at the ESO VLT in a multi-object spectroscopic mode. In addition, ESO/MPI 2.2 m WF1 and HST/ACS photometry was used. The observations were carried out within the framework of the Araucaria Project (Gieren et al 2005a, b). In the following, we discuss the analysis method and the results of this pilot study.

4. A pilot study in NGC300—analysis method

For the quantitative analysis of the spectra, KUBPGP use the same combination of line-blanketed model atmospheres and very detailed NLTE line formation calculations as Przybilla et al (2006) did in their high signal-to-noise and high spectral resolution study of galactic A supergiants, which reproduce the observed normalized spectra and the spectral energy distribution, including the Balmer jump, extremely well. They calculate an extensive, comprehensive and dense grid of model atmospheres and NLTE line formations covering the potential full parameter range of all the objects in the gravity ($log g = 0.8–2.5$), effective temperature ($T_{\text{eff}} = 8300–15000$ K) and metallicity ($[Z] = log Z/Z_{\odot} = -1.30$ to 0.3). The total grid comprises more than 6000 models.

The analysis of each of the 24 targets in NGC 300 proceeds in three steps. First, the stellar parameters ($T_{\text{eff}}$ and $log g$) are determined together with interstellar reddening and extinction; then the metallicity is determined and finally, assuming a distance to NGC 300, stellar radii, luminosities and masses are obtained. For the first step, a well-established method to obtain the stellar parameters of supergiants of the late B to early A spectral type is to use ionization equilibria of weak metal lines (OII/I; MgII/I; NI/II etc) for the determination of effective temperature $T_{\text{eff}}$ and the Balmer lines for the gravities $log g$. However, at the low resolution of 5 Å, the weak spectral lines of the neutral species disappear in the noise of the spectra and an alternative technique is required to obtain temperature information. KUBPGP confirm the result by Evans and Howarth (2003) that a simple application
of a spectral type—effective temperature relationship does not work because of the degeneracy of such a relationship with metallicity. Fortunately, a way out of this dilemma is the use of the spectral energy distributions (SEDs) and here, in particular, of the Balmer jump \(D_B\). While the observed photometry from the B-band to I-band is used to constrain the interstellar reddening, \(D_B\) turns out to be a reliable temperature diagnostic. A simultaneous fit of the Balmer lines and the Balmer jump allows one to constrain the effective temperature and gravity independent of assumptions on metallicity. Figure 1 demonstrates the sensitivity of the Balmer lines and the Balmer jump to gravity and effective temperature, respectively.

Knowing the stellar atmospheric parameters \(T_{\text{eff}}\) and \(\log g\), KUBPGP are able to determine stellar metallicities by fitting the metal lines with their comprehensive grid of line formation calculations. The fit procedure proceeds in several steps. First, the spectral windows are defined, for which a good definition of the continuum is possible and which are relatively undisturbed by flaws in the spectrum (for instance caused by cosmic events) or interstellar emission and absorption. A typical spectral window used for all targets is the wavelength interval \(4497 \text{ Å} \leq \lambda \leq 4607 \text{ Å}\). Figure 2 shows the synthetic spectrum calculated for the atmospheric parameters of target no. 21 (the previous example) and for all the metallicities of the grid ranging from \(-1.30 \leq [Z] \leq 0.30\). It is very obvious that the strengths of the metal line features are a strong function of metallicity. In figure 3, the observed spectrum of target no. 21 in this spectral region is shown overplotted by the synthetic spectrum for each metallicity separately. Bottom: \(\chi([Z])\) as obtained from the comparison of observed and calculated spectra. The solid curve is a third-order polynomial fit.

**Figure 1.** Top: model atmosphere fit of two observed Balmer lines of NGC300 target no. 21 of KUBPGP for \(T_{\text{eff}} = 10\,000\) K and \(\log g = 1.55\) (solid). Two additional models with same \(T_{\text{eff}}\) but \(\log g = 1.45\) and 1.65, respectively, are also shown (dashed). Bottom: model atmosphere fit of the observed Balmer jump of the same target for \(T_{\text{eff}} = 10\,000\) K and \(\log g = 1.55\) (solid). Two additional models with the same \(\log g\) but \(T_{\text{eff}} = 9750\) K (dashed) and 10 500 K (dotted) are also shown. The horizontal bar at 3600 Å represents the average of the flux logarithm over this wavelength interval, which is used to measure \(D_B\).

**Figure 2.** Synthetic metal line spectra calculated for the stellar parameters of target no. 21 as a function of metallicity in the spectral window from 4497 Å to 4607 Å. Metallicities range from \([Z] = -1.30\) to 0.30, as described in the text. The dashed vertical lines give the edges of the spectral window as used for a determination of metallicity.

**Figure 3.** Top: observed spectrum of target no. 21 for the same spectral window as figure 2 overplotted by the same synthetic spectra for each metallicity separately. Bottom: \(\chi([Z])\) as obtained from the comparison of observed and calculated spectra. The solid curve is a third-order polynomial fit.
shown in figure 3. The application of the same method on different spectral windows provides additional independent information on the metallicity and enables one to determine the average metallicity obtained from all windows. A value of is \([Z] = -0.39 \pm 0.15\) is obtained.

The fit of the observed photometric fluxes with the model atmospheric fluxes was used to determine the interstellar reddening \(E(B-V)\) and the extinction \(A_V = 3.1 \ E(B-V)\). Simultaneously, the fit also yields the stellar angular diameter, which provides the stellar radius, if a distance is adopted. Gieren et al (2005a, b) in their multi-wavelength study of a large sample of Cepheids in NGC 300 including the near-IR have determined a new distance modulus \(m - M = 26.37\) mag, which corresponds to a distance of 1.88 Mpc. KUBPGP have adopted these values to obtain the radii and absolute magnitudes.

5. A pilot study in NGC300—results

As a first result, the quantitative spectroscopic method yields interstellar reddening and extinction as a by-product of the analysis process. For objects embedded in the dusty disc of a star-forming spiral galaxy, one expects a wide range of interstellar reddening \(E(B-V)\) and, indeed, a range from \(E(B-V) = 0.07\) mag up to 0.24 mag was found. The individual reddening values are significantly greater than the value of 0.03 mag adopted in the HST distance scale key project study of Cepheids by Freedman et al (2001), and demonstrate the need for a reliable reddening determination of stellar distance indicators, at least as long the study is restricted to the optical wavelengths. The average over the observed sample is \(<E(B-V)> = 0.12\) mag in close agreement with the value of 0.1 mag found by Gieren et al (2005) in their optical to near-IR study of Cepheids in NGC 300. While Cepheids have somewhat lower masses than the A supergiants of our study and are consequently somewhat older, they nonetheless belong to the same population and are found at similar sites. Thus, one expects them to be affected by interstellar reddening in the same way as A supergiants.

Figure 4 shows the location of all the observed targets in the \((\log g, \log T_{\text{eff}})\) plane and in the HRD compared with the early B supergiants studied by Urbanajea et al (2005). The comparison with evolutionary tracks gives a first indication of the stellar masses in a range from \(10M_\odot\) to \(40M_\odot\). Three targets have obviously higher masses than the rest of the sample and seem to be on a similar evolutionary track to the objects studied by Urbanajea et al (2005). The evolutionary information obtained from the two diagrams appears to be consistent. The B supergiants seem to be more massive than most of the A supergiants. The same three A supergiants that are apparently more massive than the rest because of their lower gravities are also the most luminous objects. This confirms that quantitative spectroscopy is—at least qualitatively—capable of retrieving information about absolute luminosities. Note that the fact that all the B supergiants studied by Urbanajea et al (2005) are more massive is simply a selection effect of the \(V\) magnitude limited spectroscopic survey by Bresolin et al (2002). At similar \(V\) magnitude to the A supergiants, those objects have higher bolometric corrections because of their higher effective temperatures and are, therefore, more luminous and massive. 

Figure 5 shows the stellar metallicities and the metallicity gradient as a function of angular galactocentric distance, expressed in terms of the isophotal radius, \(\rho/\rho_0\)
\[(Z) = -0.06 \pm 0.09 \pm (0.083 \pm 0.022) d. \]  
\[\text{(1)}\]

Note that the metallicities of the B supergiants refer to oxygen only with a value of \(\log N(O)/N(H) = -3.31\) adopted for the Sun (Allende Prieto et al 2001). On the other hand, the A supergiant metallicities reflect the abundances of a variety of heavy elements such as Ti, Fe, Cr, Si, S and Mg. KUBPGP discuss the few outliers in figure 5 and claim that these metallicities seem to be real. Their argument is that the expectation of homogeneous azimuthal metallicity in patchy star-forming galaxies seems to be naive. Future work on other galaxies will show whether cases like this are common or not.

### 6. FGLR

Massive stars with masses in the range from 12\(M_{\odot}\) to 40\(M_{\odot}\) evolve through the B and A supergiant stage at roughly constant luminosity (see figure 4). In addition, since the evolutionary timescale is very short when crossing through the B and A supergiant domain, the amount of mass lost in this stage is small. This means that the evolution proceeds at constant mass and constant luminosity. This has a very simple, but very important consequence for the relationship of gravity and effective temperature along each evolutionary track. From

\[L \propto R^2 T_{\text{eff}}^4 = \text{constant}; \quad M = \text{constant}, \]  
\[\text{(2)}\]

it immediately follows that

\[M \propto g R^2 \propto L \quad (g/T_{\text{eff}}^4) = L_{\text{FGLR}} = \text{constant}. \]  
\[\text{(3)}\]

Thus, along the evolution through the B and A supergiant domain, the \textit{flux-weighted gravity} \(g_r = g/T_{\text{eff}}^4\) should remain constant. This means each evolutionary track of different luminosity in this domain is characterized by a specific value of \(g_r\). This value is determined by the relationship between stellar mass and luminosity, which in a first approximation is a power law given as

\[L \propto M^x \]  
\[\text{(4)}\]

and leads to a relationship between luminosity and flux-weighted gravity

\[L^{1-x} \propto (g/T_{\text{eff}}^4)^x. \]  
\[\text{(5)}\]

With the definition of bolometric magnitude \(M_{\text{bol}} \propto -2.5 \log L\), one then derives

\[- M_{\text{bol}} = a_{\text{FGLR}} (\log g_r - 1.5) + b_{\text{FGLR}}. \]  
\[\text{(6)}\]

This is the FGLR of blue supergiants. Note that the proportionality constant \(a_{\text{FGLR}}\) is given by the exponent of the mass—luminosity power law through

\[a_{\text{FGLR}} = 2.5x/(1-x). \]  
\[\text{(7)}\]

Figure 6. The FGLR of A (solid circles) and B (open circles) supergiants in NGC 300 and the linear regression (solid). The stellar evolution FGLRs for models with rotation are also overplotted (dashed: Milky Way metallicity, long-dashed: SMC metallicity).

for instance, for \(x = 3\), one obtains \(a_{\text{FGLR}} = -3.75\). Note that the zero point of the relationship is chosen at a flux-weighted gravity of 1.5, which is in the middle of the range encountered for blue supergiant stars.

KUBPGP use the mass—luminosity relationships of different evolutionary tracks (with and without rotation, for Milky Way and SMC metallicity) to calculate the different FGLRs predicted by stellar evolution. Very interestingly, while different evolutionary model types yield somewhat different FGLRs, the differences are rather small.

Kudritzki et al (2003) were the first to realize that the FGLR has very interesting potential as a purely spectroscopic distance indicator, as it relates two spectroscopically well-defined quantities, effective temperature and gravity, to the absolute magnitude. Compiling a large dataset of spectroscopic high-resolution studies of A supergiants in the Local Group and with an approximate analysis of low-resolution data of a few targets in galaxies beyond the Local Group (see discussion in previous chapters), they were able to prove the existence of an observational FGLR rather similar to the theoretically predicted one.

With the improved analysis technique of low-resolution spectra of A supergiants and with the much larger sample studied for NGC 300, KUBPGP resumed the investigation of the FGLR.

The result is shown in figure 6, which for NGC 300 reveals a clear and rather tight relationship of flux-weighted gravity \(\log g_r\) with bolometric magnitude \(M_{\text{bol}}\). A simple linear regression yields \(b_{\text{FGLR}} = 8.11\) for the zero point and \(a_{\text{FGLR}} = -3.52\) for the slope. The standard deviation of this relationship is \(\sigma = 0.34\) mag. Within the uncertainties, the observed FGLR appears to be in agreement with the theory.

In their first investigation of the empirical FGLR Kudritzki et al (2003) have added A supergiants from six Local Group galaxies with stellar parameters obtained from quantitative studies of high-resolution spectra (Milky Way, LMC, SMC, M31, M33 and NGC 6822) to their results for NGC 300 to obtain a larger sample. They also added four objects from the spiral galaxy NGC 3621 (at 6.7 Mpc), which

\[\rho = 5.33 \text{ kpc}. \]  
\[\text{(d)}\]

Despite the scatter caused by the metallicity uncertainties of the individual stars, the metallicity gradient of the young disk population in NGC 300 is very clearly visible. A linear regression for the combined A and B supergiant sample yields \((d \text{ in kpc})\)

\[\text{(f)}\]
were studied at low resolution. KUBPGP added exactly the same dataset to their new enlarged NGC 300 sample, however, with a few minor modifications. For the Milky Way, they included the latest results from Przybilla et al (2006) and Schiller and Przybilla (2008). For the objects in NGC 3621, they applied new HST photometry. They also re-analysed the LMC objects using ionization equilibria for the determination of temperature.

Figure 7 (right diagram) shows bolometric magnitudes and flux-weighted gravities for this full sample of eight galaxies revealing a tight relationship over one order of magnitude in the flux-weighted gravity. The linear regression coefficients are $a_{\text{FGLR}} = -3.41 \pm 0.16$ and $b_{\text{FGLR}} = 8.02 \pm 0.04$, very similar to the NGC 300 sample alone. The standard deviation is $\sigma = 0.32$ mag. The stellar evolution FGLR for Milky Way metallicity provides a fit of almost similar quality with a standard deviation of $\sigma = 0.31$ mag.

7. Conclusions and future work

The astrophysical potential of low-resolution spectroscopy of A supergiant stars for studying galaxies beyond the Local Group is quite remarkable. By introducing a novel method for quantitative spectral analysis, one is able to determine accurate stellar parameters that allow for a detailed test of stellar evolution models. Through the spectroscopic determination of stellar parameters, one can also constrain interstellar reddening and extinction by comparing the calculated SED with broad-band photometry. The study of NGC 300 finds a very patchy extinction pattern as to be expected for a star-forming spiral galaxy. The average extinction is in agreement with multi-wavelength studies of Cepheids including K-band photometry.

The method also allows one to determine stellar metallicities and to study stellar metallicity gradients. Solar metallicity is found in the centre of NGC 300 and at a gradient of $-0.08$ dex kpc$^{-1}$. To our knowledge, this is the first systematic stellar metallicity study in galaxies beyond the Local Group focusing on iron group elements. In the future, the method can be extended to not only determine metallicity but also the ratio of $\alpha$- to iron-group elements as a function of galactocentric distance. The stellar metallicities obtained can be compared with oxygen abundance studies of HII regions using the strong line method. This enables one to discuss the various calibrations of the strong line method, which usually yield very different results.

The improved spectral diagnostic method makes it possible to very accurately determine stellar flux-weighted gravities $\log g_{\text{F}} = \log g_{\text{eff}}/T_{\text{eff}}^4$ and bolometric magnitudes. Above a certain threshold in effective temperature, a simple measurement of the strengths of the Balmer lines can be used to determine accurate values of $\log g_{\text{F}}$.

Absolute bolometric magnitudes $M_{\text{bol}}$ and flux-weighted gravities $\log g_{\text{F}}$ are tightly correlated. It is shown that such a correlation is expected for stars, which evolve at constant luminosity and mass. This FGLR shows agreement with the stellar evolution theory.

With a relatively small residual scatter of $\sigma = 0.3$ mag, the observed FGLR is an excellent tool to determine accurate spectroscopic distance to galaxies. It requires multi-colour photometry and low-resolution (5 Å) spectroscopy to determine the effective temperature and gravity and, thus, the flux-weighted gravity directly from the spectrum. With the effective temperature, gravity and metallicity determined, one also knows the bolometric correction, which is small for A supergiants, which means that errors in the stellar parameters do not largely affect the determination of bolometric magnitudes. Moreover, one knows the intrinsic stellar SED and, therefore, can determine interstellar reddening and extinction from multi-colour photometry, which then allows for the accurate determination of the reddening-free apparent bolometric magnitude. The application of the FGLR then yields absolute magnitudes and, thus, the distance modulus. With the intrinsic scatter of $\sigma = 0.3$ mag and 30 targets per galaxy, one can achieve an estimation accuracy of 0.05 mag in the distance modulus (0.1 mag for 10 target stars). The results for WLM (see figure 8) by Urbaneja et al (2008) and
for M33 by U, Urbaniaja et al are the first demonstrations of the power of the method.

The advantage of the FGLR method for distance determination is its spectroscopic nature, which provides significantly more information about the physical status of the objects used for the distance determination than single photometric methods. Most importantly, metallicity and interstellar extinction can be determined directly. The latter is crucial for spiral and irregular galaxies because of the intrinsic patchiness of reddening and extinction.

Since supergiant stars are known to show intrinsic photometric variability, the question arises whether the FGLR method is affected by such variability. For the targets in NGC 300, this issue has been carefully investigated by Bresolin et al (2004), who studied CCD photometric light curves obtained over many epochs in the parallel search for Cepheids in NGC 300. They concluded that amplitudes of photometric variability are very small and do not affect distance determinations using the FGLR method.

The effects of crowding and stellar multiplicity are also important. However, in this regard A supergiants offer tremendous advantages relative to other stellar distance indicators. First of all, they are significantly brighter. Bresolin et al (2005), using HST ACS photometry in comparison with ground-based photometry, have studied the effects of crowding on the Cepheid distance to NGC 300 and concluded that they are negligible. With A supergiants being 3 to 6 magnitudes brighter than Cepheids, it is clear that even with ground-based photometry only crowding is generally not an issue for these objects at the distance of NGC 300 and, moreover, with HST photometry (and in the future JWST) one can reach much larger distances before crowding becomes significant. In addition, any significant contribution by additional objects to the light of an A supergiant will become apparent in the spectrum, if the contaminants are not of a very similar spectral type, which is very unlikely because of the short evolutionary lifetime in the A supergiant stage. It is also important to note that A supergiants have evolutionary ages greater than 10 million years, which means that they have time to migrate into the field or that they are found in older clusters that are usually less concentrated than the very young OB associations.

It is evident that the type of work described in this paper can be extended in a straightforward manner to the many spiral galaxies in the local volume at distances in the 4 to 7 Mpc range. Bresolin et al (2001) have already studied A supergiants in NGC 3621 at a distance of 7 Mpc. Pushing the method, we estimate that with present day 8–10 m class telescopes and the existing very efficient multi-object spectrographs, one can reach down with sufficient S/N to \( V = 22.5 \) mag, in two nights of observing time under very good conditions. For objects brighter than \( M_V \approx -8 \) mag, this indicates metallicities and distances can be determined out to distances of 12 Mpc \( (m - M = 30.5 \text{ mag}) \). This opens up a substantial volume of the local universe for metallicity and galactic evolution studies and independent distance determinations complementary to the existing methods. With the next generation of extremely large telescopes such as the TMT, GMT or the E-ELT, the limiting magnitude can be pushed to \( V = 24.5 \) equivalent to distances of 30 Mpc \( (m - M = 32.5 \text{ mag}) \).

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