Quantitative Spectroscopy of Local Group Supergiants

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Abstract. High-resolution spectroscopy of luminous blue supergiants in Local Group galaxies has become feasible with the new generation of 8-10m class telescopes and dedicated instrumentation (VLT/UVES and Keck/HIRES). We present a (re)analysis of objects in NGC 6822 and M 31 by non-LTE/LTE spectrum synthesis. Detailed stellar parameters, chemical abundances, stellar wind properties and reddening values of single stars in different galactic environments are obtained. This work is a case study for analyses of future observations with efficient multi-object facilities like FLAMES on the VLT that will allow an effective use of telescope time.

1 Introduction

Luminous BA-type supergiants are the visually brightest stars in spiral and irregular galaxies (up to $M_V = -10$). They are accessible to high-resolution spectroscopy within the Local Group galaxies and thus offer a unique opportunity to study individual stars within different galactic environments in detail. Besides stellar parameters, a wealth of data on individual chemical abundances, stellar wind properties and the reddening of the objects is gained. Beyond the Magellanic Clouds, supergiants in NGC 6822, M 31 and M 33 have been studied, e.g. [1–4]. Observations of larger ensembles of supergiants in galaxies will allow a number of vital questions to be addressed: stellar evolution models at different metallicities (He and CNO mixing); galactic abundance patterns and gradients; mapping of the reddening; and the metallicity dependence of the wind momentum-luminosity relationship (WLR) [5].

2 First results

The quantification of non-LTE effects is crucial for accurate analyses of supergiant spectra as the common assumption of LTE can introduce large systematic errors when studying objects close to the Eddington limit. In order to improve the situation, non-LTE effects for a number of elements have been studied from

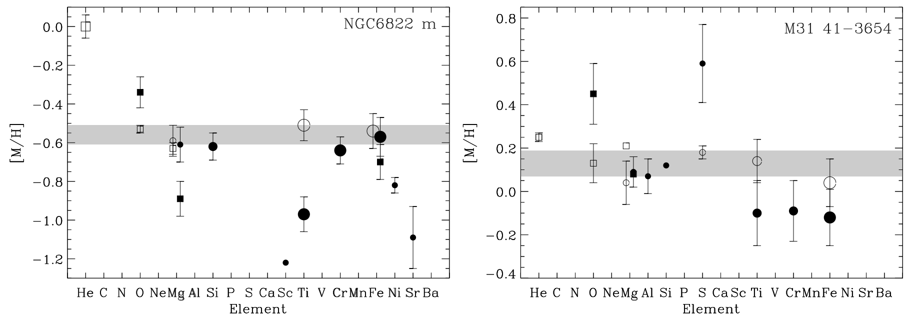

Fig. 1. Non-LTE and LTE (*open and filled symbols*) abundances [M/H] = log(M/H) − log(M/H)$_\odot$ for neutral (*boxes*) and singly-ionized species (*circles*) in two sample supergiants. The error bars represent 1σ–uncertainties from the line–to–line scatter; the grey shaded area marks the deduced stellar metallicity within 1σ–errors. The analyses are based on the following stellar parameters: $T_{\rm eff} = 9000/9250$ K, $\log g = 1.40/1.10$ (cgs), $\xi = 4/8\,{\rm km\,s^{-1}}$, $y = 0.09/0.145$ (helium, by number) for NGC 6822 m/M 31 41-3654; reddening values of $E(B-V) = 0.40/0.14$ are derived

high-resolution, high-S/N spectra of Galactic supergiants (Przybilla, Ph.D. thesis, in preparation, and also [6–8] for a discussion of the analysis techniques and first results). However, the metallicity dependence of non-LTE effects can only be constrained by analyses of stars in different galactic environments, where also the most luminous objects can be easily identified. Here, we report on an extended non-LTE (re)analysis of early A-type supergiants in M 31, objects '41-3712' and '41-3654' from [1], and in the metal-poor environment of NGC 6822, object 'm' from [2].

Good agreement with the LTE results published in [1] is found for the A3 Iae object 41-3712, at roughly solar metallicity. Here, non-LTE effects on the abundance determination tend to be small (generally well below 0.2 dex). The results for the other two supergiants of spectral type A2 Ia (NGC 6822 m) and A1 Iae (41-3654) are summarised in Fig. 1. Accounting for non-LTE effects reduces the random errors and removes systematic trends in the elemental abundances. The non-LTE abundances (relative to the solar composition [9]) cluster in a tight band around a mean value, which we identify with the stellar metallicity, whereas the LTE abundances show a large scatter. The most notable feature at the low metallicity of NGC 6822 is the large overionization of Ti II, while other species like Fe II are hardly affected by non-LTE, as this star is a normal supergiant of not too high luminosity. Close to the Eddington limit the non-LTE effects generally increase and become non-negligible for all the elements investigated. Indeed, in the case of M 31 41-3654, the most luminous star in the sample, an LTE analysis completely fails to give consistent abundances. Moreover, the LTE analysis would misleadingly indicate an enhanced α-element (Mg, S) over iron ratio [α/Fe], solely due to systematic errors. This example clearly demonstrates the importance of non-LTE effects on supergiant analyses. Apart from the recent progress, further studies on non-LTE effects in other diagnostic elements are needed in order to fully exploit blue supergiants as tracers of galactochemical evolution, e.g. for Sr, the primary indicator for the s-process elements at these spectral types.

Helium appears to be enriched in all three stars. However, the most sensitive elements to mixing processes, carbon and nitrogen, are missing in the present analysis, as the diagnostic lines are located outside the wavelength range covered. Additional observations are therefore needed in order to address the evolutionary status of these supergiants.

The results from the stellar wind analysis of the two M 31 supergiants are displayed in Fig. 3 of Bresolin et al. (this proceedings). Spherically-extended, hydrodynamic H+He non-LTE models atmospheres [10] are used to model the wind-dominated H_α-profile. Both stars lie on the Galactic WLR, in accordance with their metallicity. H_α in NGC 6822 m does not show the characteristic P-Cygni-profile, being the indicator for strong mass-loss. The lower luminosity of this star, in combination with the intrinsically lower metallicity of NGC 6822, favours the scenario of a weak wind.

3 The VLT perspective

Studies of supergiants in Local Group galaxies beyond the Magellanic Clouds presently suffer from low number statistics, as the exposure times for single objects are large, up to a whole night to comply with the S/N and wavelength coverage requirements. Multi-object facilities like FLAMES on the VLT, in combination with the GIRAFFE spectrograph, will have a large impact on the field of quantitative spectroscopy in nearby galaxies through multiplexing factors of more than ten. Spectra of the whole supergiant population of single dwarf irregular galaxies will be obtained within typically several nights of observing time.

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