RevMexAA (Serie de Conferencias), **33**, 169–170 (2008)

EXTRAGALACTIC STELLAR ASTRONOMY WITH BLUE SUPERGIANTS

N. Przybilla,[1] F. Bresolin,[2] K. Butler,[3] R. P. Kudritzki,[2] M. A. Urbaneja,[2] and K. A. Venn[4]

RESUMEN

La generación actual de grandes telescopios permite el estudio espectroscópico de estrellas supergigantes azules en galaxias incluso más allá del Grupo Local. Recientes avances en las técnicas de síntesis espectral en NLTE permiten una determinación precisa de los parámetros estelares y las abundancias químicas. El análisis cuantitativo de estas estrellas en diversos entornos galácticos puede proporcionar límites observacionales restrictivos en diversos campos: (I) la evolución de estrellas masivas en un rango amplio de metalicidades, (II) la evolución química de diversos tipos de galaxias mediante el uso de estas estrellas como trazadores de los gradientes de abundancias, (III) la escala de distancias extragaláctica. En la presente contribución resumimos el estado actual de este campo de investigación.

ABSTRACT

The present generation of large telescopes facilitates spectroscopy of blue supergiants in galaxies out to distances beyond the Local Group. Recent developments in NLTE spectrum synthesis techniques allow for an accurate determination of stellar parameters and chemical abundances. Quantitative analyses of blue supergiants in different galactic environments can provide tight observational constraints on: (I) the evolution of massive stars over a wide range of metallicities, (II) the chemical evolution of different galaxy types, using stars as tracers of abundance gradients, (III) the extragalactic distance scale. The current status of the field is summarised.

Key Words: distance scale — galaxies: abundances — stars: abundances — stars: evolution — stars: fundamental parameters — supergiants

1. MOTIVATION

Massive blue supergiants (BSGs) of spectral types B and A are among the visually brightest stars in spiral and irregular galaxies. In the era of large telescopes, this makes them primary candidates for spectroscopic studies even when situated in galaxies well beyond the Local Group. Information on fundamental stellar parameters and abundances for a wide variety of chemical species (CNO, iron group elements, α- and s-process elements) can thus be obtained. The challenges for the quantitative analysis are posed by the high energy and momentum density of the radiation field in a tenuous atmosphere, requiring NLTE modelling techniques.

Analyses of samples of BSGs in different galactic environments allow observational constraints on the evolution of massive stars and galactochemical evolution to be derived. Abundances of the light elements (He, CNO) act as tracers of rotational mixing (e.g. Maeder & Meynet 2000) and may help to constrain the complex (magneto-)hydrodynamic processes relevant to stellar evolution empirically. The step to other galaxies is required in order to test for metallicity effects. Furthermore, BSGs can act as tracers of abundance gradients, which allow us to discriminate between different models of galactochemical evolution (e.g. Chiappini et al. 2001). The stellar results may be used to verify – but also to extend – studies of H II regions. Finally, tighter constraints on the extragalactic distance scale can be expected from spectroscopic analyses of BSGs. Systematic uncertainties (metallicity, reddening effects) that are of concern for classical photometric indicators like the period-luminosity relationship for Cepheids may thus be avoided.

2. MODELLING & RESULTS

We follow two approaches in modelling the atmospheres of BSGs. The photospheric spectra of less-luminous A-type SGs can be modelled well with classical line-blanketed LTE model atmospheres using NLTE line formation for specific elements (Venn 1995). It has been shown that this hybrid NLTE approach can be extended to objects of higher luminosity and also into the regime of late

[1]Dr. Remeis Sternwarte Bamberg, Sternwartstr. 7, 96049 Bamberg, Germany (przybilla@sternwarte.uni-erlangen.de).

[2]Institute for Astronomy, 2680 Woodlawn Drive Honolulu, Hawaii 96822, USA.

[3]Universitäts-Sternwarte München, Scheinerstr. 1, 81679 München, Germany.

[4]University of Victoria, Elliott Building, 3800 Finnerty Road, Victoria, BC, V8P 1A1, Canada.

B-type SGs (Przybilla et al. 2006). A new generation of state-of-the-art NLTE model atoms (Przybilla & Butler 2001, 2004; Przybilla et al. 2000, 2001ab; Nieva & Przybilla 2006) allows stellar parameters and elemental abundances to be derived with unprecedented accuracy: effective temperature $T_{\rm eff}$ to better than 1–2%, surface gravity $\log g$ to 0.05–0.10 dex and abundances to ∼0.05–0.10 dex (random) and ∼0.10 dex (systematic uncertainties). Multiple NLTE ionization equilibria, Stark-broadened hydrogen profiles and spectral energy distributions are simultaneously matched. Massive (NLTE) spectrum synthesis allows us to reproduce practically the entire observed high-resolution spectra in the visual, a prerequisite for applications of the method to intermediate-resolution data, in that case however at reduced accuracy. Early B-type SGs are modelled with line-blanketed NLTE-model atmospheres accounting for hydrodynamical outflow and spherical extension (Puls et al. 2005; Urbaneja et al. 2005b). This allows the photospheric spectra and the stellar wind features to be analysed in a self-consistent manner. Galactic BSGs are crucial test cases for the analysis methodology, as detailed comparisons of theory with high-quality spectra are feasible only here.

Studies of abundance patterns of the light elements as tracers for rotational mixing in BSGs beyond the Milky Way have concentrated on the metal-poor SMC (Venn 1999; Trundle & Lennon 2005) and M 33 (Urbaneja et al. 2005b). The findings confirm predictions of stellar evolution calculations that the efficiency of mixing processes increases with decreasing metallicity in a qualitative way. However, there remain discrepancies between observational findings and predictions on the amount of mixing.

Abundance studies on heavier elements have been performed for a few objects in more distant galaxies of the Local Group at high spectral resolution using Keck/HIRES and VLT/UVES: in M 31, NGC 6822 and WLM (Venn et al. 2000, 2001, 2003) and in Sextans A in the closeby Sextans-Antlia Group (Kaufer et al. 2004). Good agreement of stellar and nebular abundances (mostly oxygen) is found in most cases, in both spiral and dwarf irregular galaxies. The low [α/Fe] ratios are consistent with the slow chemical evolution expected for dwarf galaxies.

Spectroscopic surveys at intermediate resolution using long-slit (WHT/ISIS) and multi-object spectrographs (VLT/FORS) have produced a considerable amount of data on BSGs in the Local Group (M 31: Trundle et al. 2002; M 33: Urbaneja et al. 2005b; WLM: Bresolin et al. 2006). Beyond the Local Group, the investigations have concentrated so far on the Sculptor Group spiral NGC 300 (Bresolin et al. 2002; Urbaneja et al. 2005a) and the field spiral NGC 3621 (Bresolin et al. 2001) at a distance of 6.6 Mpc. The quantitative analysis of subsets of these stars finds in general reasonably good agreement with published abundances from studies of nebulae. However, systematic offsets may occur. In particular some statistical indicators (R_{23}–O/H-calibrations) for nebular abundances are shown to be prone to systematic error when compared to stellar abundances or nebular abundances from H II regions with direct $T_{\rm e}$ determinations (Urbaneja et al. 2005a). Both, absolute abundances and the slope of the abundance gradient may be affected.

Finally, it has been shown that BSGs can be used as spectroscopic distance indicators, via application of the wind momentum-luminosity relationship (WLR, e.g. Kudritzki et al. 1999) and the flux-weighted gravity-luminosity relationship (FGLR, Kudritzki et al. 2003). Both methods have the potential to facilitate measurements of distance moduli out to systems in the Virgo and Fornax clusters of galaxies with an accuracy of 0.1 mag or better, once properly calibrated. The intrinsic photometric variability of BSGs have been shown to have a negligible effect on the FGLR (Bresolin et al. 2004, 2006).

REFERENCES

Bresolin, F., et al. 2001, ApJ, 548, L159
———. 2002, ApJ, 567, 277
———. 2004, ApJ, 600, 182
———. 2006, ApJ, 648, 1007
Chiappini, C., et al. 2001, ApJ, 554, 1044
Kaufer, A., et al. 2004, AJ, 127, 2723
Kudritzki, R. P., et al. 1999, A&A, 350, 970
———. 2003, ApJ, 582, L83
Maeder, A., & Meynet, G. 2000, ARA&A, 38, 143
Nieva, M. F. & Przybilla, N. 2006, ApJ, 639, L39
Przybilla, N. & Butler, K. 2001, A&A, 379, 955
———. 2004, ApJ, 609, 1181
Przybilla, N., et al. 2000, A&A, 359, 1085
———. 2001a, A&A, 369, 1009
———. 2001b, A&A, 379, 936
———. 2006, A&A, 445, 1099
Puls, J., et al. 2005, A&A, 435, 669
Trundle, C. & Lennon, D. J. 2005, A&A, 434, 677
Trundle, C., et al. 2002, A&A, 395, 519
Urbaneja, M. A., et al. 2005a, ApJ, 622, 862
———. 2005b, ApJ, 635, 311
Venn, K. A. 1995a, ApJS, 99, 659
———. 1999, ApJ, 518, 405
Venn, K. A., et al. 2000, ApJ, 541, 610
———. 2001, ApJ, 547, 765
———. 2003, AJ, 126, 1326