The Magellanic System: Stars, Gas, and Galaxies
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Quantitative spectroscopy of BA-type supergiants in the SMC: Basic atmospheric parameters and the flux-weighted gravity–luminosity relationship

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Abstract. BA-type supergiants are among the visually brightest stars in galaxies, facilitating quantitative spectroscopy well beyond the Local Group (Bresolin et al. 2001, 2002). They are powerful distance indicators via application of the flux-weighted gravity–luminosity relationship (FGLR, Kudritzki et al. 2003).

The FGLR relates purely spectroscopic quantities such as effective temperature $T_{\rm eff}$ and surface gravity $\log(g)$ to absolute magnitudes, providing an independent distance estimate. The FGLR promises tighter constraints on the extragalactic distance scale to be derived than possible with classical photometric indicators such as Cepheids, as reddening and metallicity can be determined in a comprehensive spectral analysis. In order to use this potential, a careful calibration of the FGLR — in different galactic environments — is required.

For this, we investigate fundamental properties of 23 late-B and early-A type supergiants in the Small Magellanic Cloud (SMC) on the basis of high-resolution, high-S/N FEROS spectra. The nearby SMC is of particular interest as it is the only galaxy in which high-quality spectra of *metal-poor* BA-type supergiants can be obtained with ease. Effective temperatures and surface gravities are derived from a detailed analysis of metal ionization equilibria and the Stark-broadened Balmer lines using an extensive non-LTE model grid of synthetic spectra.

Keywords. stars: early-type, stars: supergiants, stars: fundamental parameters, Magellanic Clouds

1. Theoretical motivation of the FGLR

Massive stars from $\approx 12\,{\rm M}_\odot$ to $\approx 40\,{\rm M}_\odot$ evolve through the BA-type supergiant stage at almost constant luminosity. Moreover, considering the short evolutionary timescale for stars crossing trough this domain of the HRD one can also assume a constant stellar mass. This has interesting consequences for the relationship of gravity and effective temperature. From

$$L \propto R^2 T_{\rm eff}^4 = \text{constant}; \qquad M = \text{constant} \tag{1.1}$$

follows that

$$M \propto gR^2 \propto L \cdot \frac{g}{T_{\rm eff}^4} = L g_{\rm F} = \text{constant} \tag{1.2}$$

indicating a constant flux-weighted gravity

$$g_{\rm F} = \frac{g}{T_{\rm eff}^4} \tag{1.3}$$

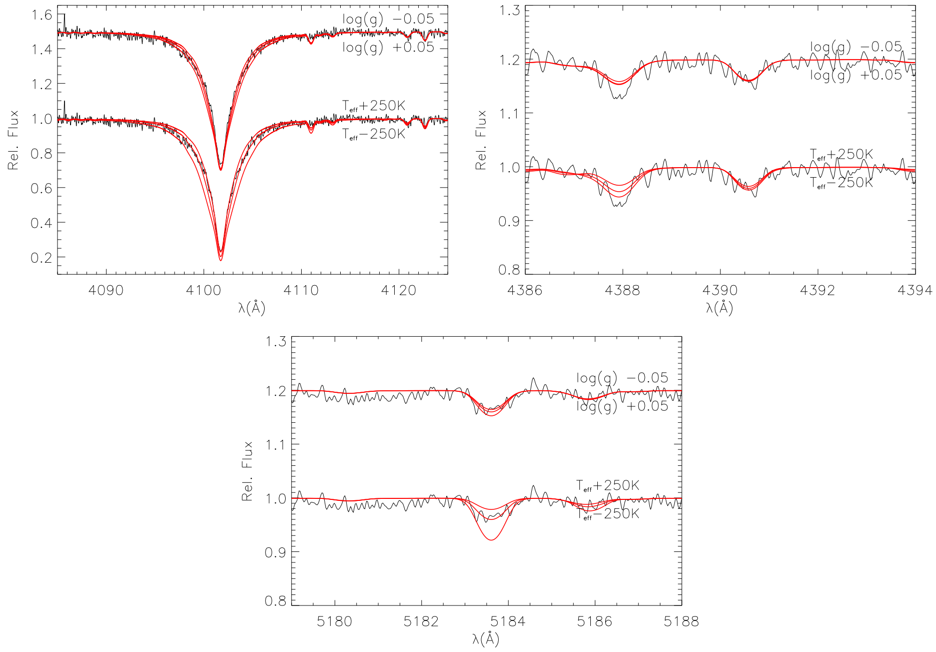

Figure 1. Examples of fits with our hybrid non-LTE approach for final and modified (at the amount of differences to the nearest grid points, which correspond to typical uncertainties) parameters to various lines of an observed spectrum. *Top, left*: H_δ; *top, right*: He I (at ≈ 4388 Å) and Mg II (at ≈ 4390 Å); *bottom*: Mg I.

for the evolution at constant luminosity through the BA-type supergiant domain. This means also that during this whole evolutionary phase the luminosity of a star is fully determined by its effective temperature and surface gravity — two basic parameters of stellar atmospheres which can be determined through spectral analyses.

Expressed in absolute bolometric magnitude $M_{\rm bol} \propto 2.5 \log L$, the *flux-weighted gravity–luminosity relationship* adopts the following form

$$-M_{\rm bol} = a_{\rm FGLR}(\log g_{\rm F} - 1.5) + b_{\rm FGLR} \qquad \text{(FGLR)} \tag{1.4}$$

where $a_{\rm FGLR}$ is determined by the mass–luminosity relationship. For a calibration of the FGLR, $g_{\rm F}$ as well as $M_{\rm bol}$ have to be determined. While $g_{\rm F}$ is obtained through the spectral analysis, an independent assumption for the distance is necessary in order to obtain a value for $M_{\rm bol}$ for each star:

$$M_{\rm bol} = m_{\rm V} - (m_{\rm V} - M_{\rm V})_0 + B.C. - A_{\rm V} \tag{1.5}$$

The bolometric correction $B.C.$ is derived from models while the extinction $A_{\rm V}$ is obtained from the comparison of observed and theoretical colors. We adopt a value of 19.0 for the distance modulus $(m_{\rm V} - M_{\rm V})_0$ to the SMC.

2. Methods and model calculations

Effective temperatures and surface gravities are derived from a comparison of observations (high-resolution, high-S/N spectra obtained with FEROS on the 2.2 m telescopein La Silla) with synthetic spectra from an extensive grid of hybrid non-LTE models. These were computed on the basis of line-blanketed LTE model atmospheres (ATLAS9) with

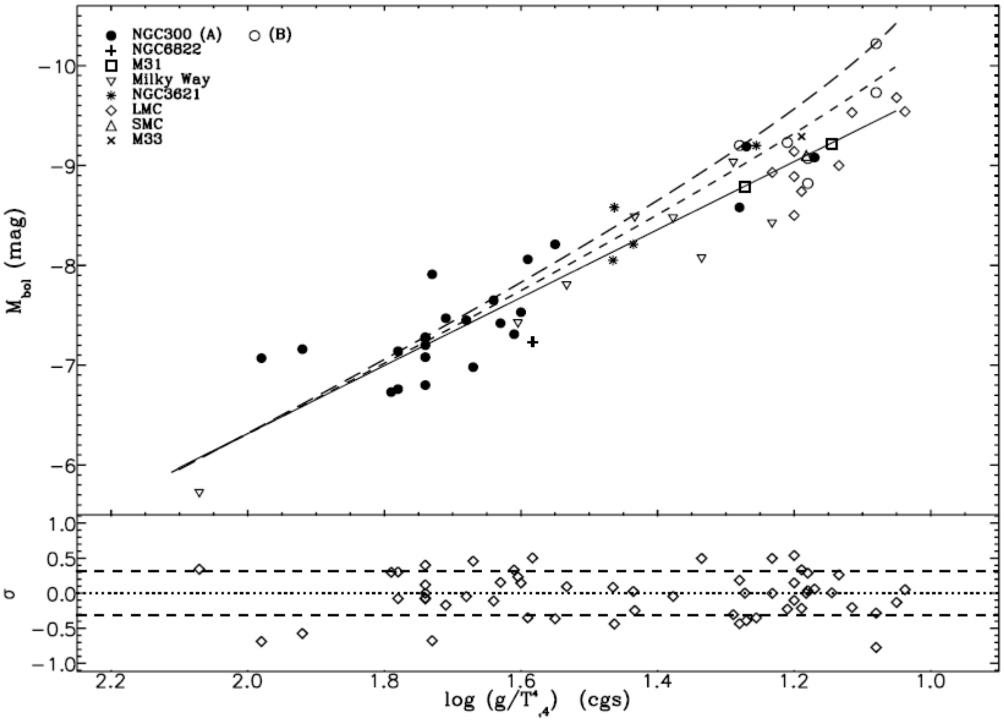

Figure 2. The figure shows flux-weighted gravities and absolute bolometric magnitudes from Kudritzki et al. (2008) for their sample of stars in various galaxies. A linear fit (*solid line*) reveals a slope of the FGLR of −3.41. The stellar evolution FGLRs (Meynet & Maeder 2005) for models with rotation are superimposed (*dashed*: Milky Way metallicity, *long-dashed*: SMC metallicity). They are in good agreement with the observational results.

subsequent non-LTE line formation with DETAIL and SURFACE (see Przybilla et al. (2006) and Kudritzki et al. (2008) for details). Simultaneous use of Stark-broadened Balmer lines as well as metal ionization equilibria allows for a precise determination of the stellar parameters and thus for a precise calibration of the flux-weighted gravity luminosity relationship itself (see Fig. 1).

3. State-of-the-art of the FGLR

The state-of-the-art of the FGLR from the observational point of view as well as predictions from stellar evolution theory are shown in Fig. 2. The theoretical FGLRs are slightly curved because of a small variation of the mass–luminosity relationship at different g_F values.

4. Results and Discussion

Fig. 3 shows preliminary results for our observed objects. Several objects had to be omitted for the moment as the spectral features indicated atmospheric parameters beyond the limits of our non-LTE grid in terms of temperature range and helium abundance. These are among the brightest stars in the SMC, having the lowest $\log g_F$-values. This leads to a selection effect, rendering the basis in $\log g_F$ too small for a comprehensive analysis.

Therefore, we cannot present a significant value for the slope of the FGLR at the

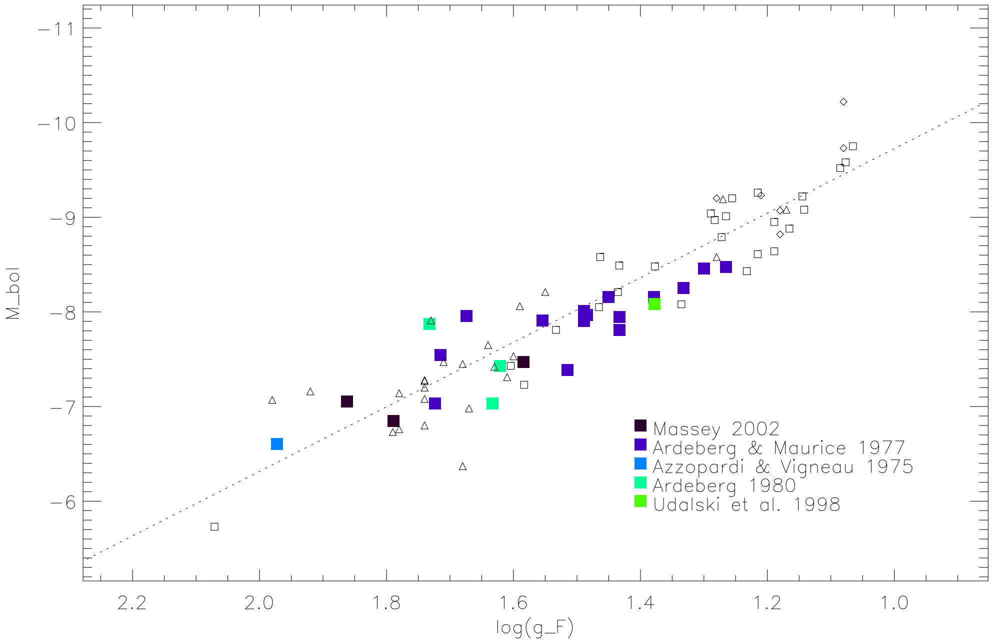

Figure 3. Our sample stars from the SMC are plotted as *filled* symbols where the color is indicating the source of the apparent visual magnitudes. Superimposed are the supergiants of Kudritzki et al. (2008) as *small open* symbols together with their linear regression.

moment. However, adopting the slope $a_{\rm FGLR} = -3.41$ from Kudritzki et al. (2008), we can determine the zero point $b_{\rm FGLR}$ to 7.91 ± 0.07. Within the errors, this agrees with $b_{\rm FGLR} = 8.02 \pm 0.04$ from Kudritzki et al. (2008). Further discussions will have to wait until the full sample can be analysed.

References

Bresolin, F., Kudritzki, R.-P., Méndez, R.H., & Przybilla, N. 2001, *ApJ*, 548, L159

Bresolin, F., Gieren, W., Kudritzki, R.P., Pietrzyński, G., & Przybilla, N. 2002, *ApJ*, 567, 277

Kudritzki, R.P., Bresolin, F., & Przybilla, N. 2003, *ApJ*, 582, L83

Kudritzki, R.-P., Urbaneja, M.A., Bresolin, F., Przybilla, N., Gieren, W., & Pietrzyński, G. 2008, *ApJ*, 681, 269

Massey, P. 2002, *ApJS*, 141, 81

Meynet, G., & Maeder, A. 2005, *A&A*, 429, 581

Przybilla, N., Butler, K., Becker, S.R., & Kudritzki, R.P. 2006, *A&A*, 445, 1099