Stellar Lunch

Blue Supergiants as distance and stellar metallicity measures in the Local Volume

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Abstract

Rolf Kudritzki and co-workers at the IfA, University of Hawaii (and elsewhere) have, over the past 14 years, been developing techniques to use low resolution spectroscopy of distant B-A supergiants to measure stellar metallicity, surface gravities, reddening and extinction, absolute bolometric magnitudes and distances. With the current 8-10 metre class telescopes the technique permits these measurements out to distances approaching 10Mpc. This talk will be about their latest methods and their basis.

TABLE 1

Adopted Temperature Scale

Spectral Type	$T_{\rm eff}$ (K)
B8	12000
B9	10500
A0	9500
A1	9250
A2	9000
A3	8500
A4	8350

Figure 1: from Kudritzki et al. (2003)

Massive stars during their evolution toward the red supergiant stage pass through the phase of late B and early A supergiants quickly and with roughly constant mass and luminosity (Meynet & Maeder 2000; Meynet et al. 1994; Heger & Langer 2000). This means that in this phase the stellar gravity g and effective temperature $T_{\rm eff}$ are coupled through the condition $g/T_{\rm eff}^4 =$ const. We call $g/T_{\rm eff}^4$ the "flux-weighted gravity." Assuming that mass and luminosity follow the usual relation $L \propto M^\alpha$ ($\alpha \sim 3$), we derive a relationship between absolute bolometric magnitude $M_{\rm bol}$ and the flux-weighted gravity of the form

$$-M_{\rm bol} = a \log (g/T_{\rm eff}^4) + b, \tag{1}$$

with a of the order of -3.75. This means that for these spectral types the fundamental stellar parameters of effective temperature and gravity are tightly coupled to the absolute magnitude rendering the possibility of purely spectroscopic distance determination. In the following, we refer to equation (1) as the "flux-weighted gravity–luminosity relationship" (FGLR).

Figure 2: from Kudritzki et al. (2003)

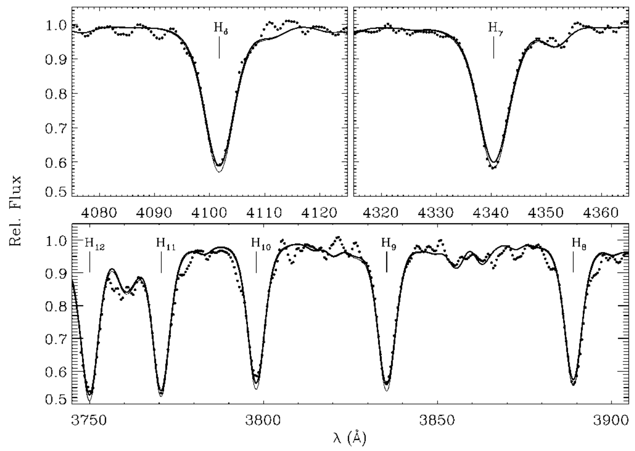

FIG. 1.—Fit of the Balmer lines Hγ,δ and H8 to H11 of the NGC 300 A0 Ia supergiant C6 (see Bresolin et al. 2002) using atmospheric models with $T_{\rm eff}$ = 9500 K and log g = 1.60 (*thick line*) and 1.65 (*thin line*) (gravities given in cgs units). Note that the use of information from many Balmer lines enhances the accuracy of the log g determination significantly. The FWHM of the instrumental profile is ~5 Å, which is larger than the intrinsic width of the Balmer lines and the line broadening through rotation (typically ≤50 km s^{-1} for A supergiants). Therefore, the calculations are convolved with the instrumental profile. This explains why gravity effects cannot be seen in the line wings but only in the cores. These effects in the line cores reflect the changes of the integrated absorption-line strength (equivalent width) as a function of gravity.

Figure 3: from Kudritzki et al. (2003)

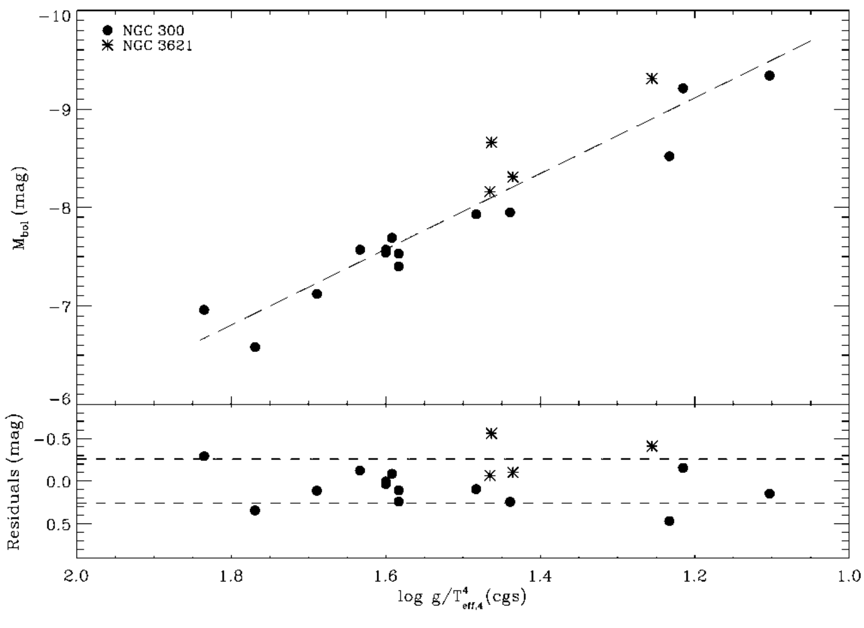

FIG. 2.—Absolute bolometric magnitude vs. logarithm of flux-weighted gravity of B8 to A4 supergiants in NGC 300 and NGC 3621. Note that $T_{\rm eff}$ is used in units of 10^4 K.

Figure 4: from Kudritzki et al. (2003)

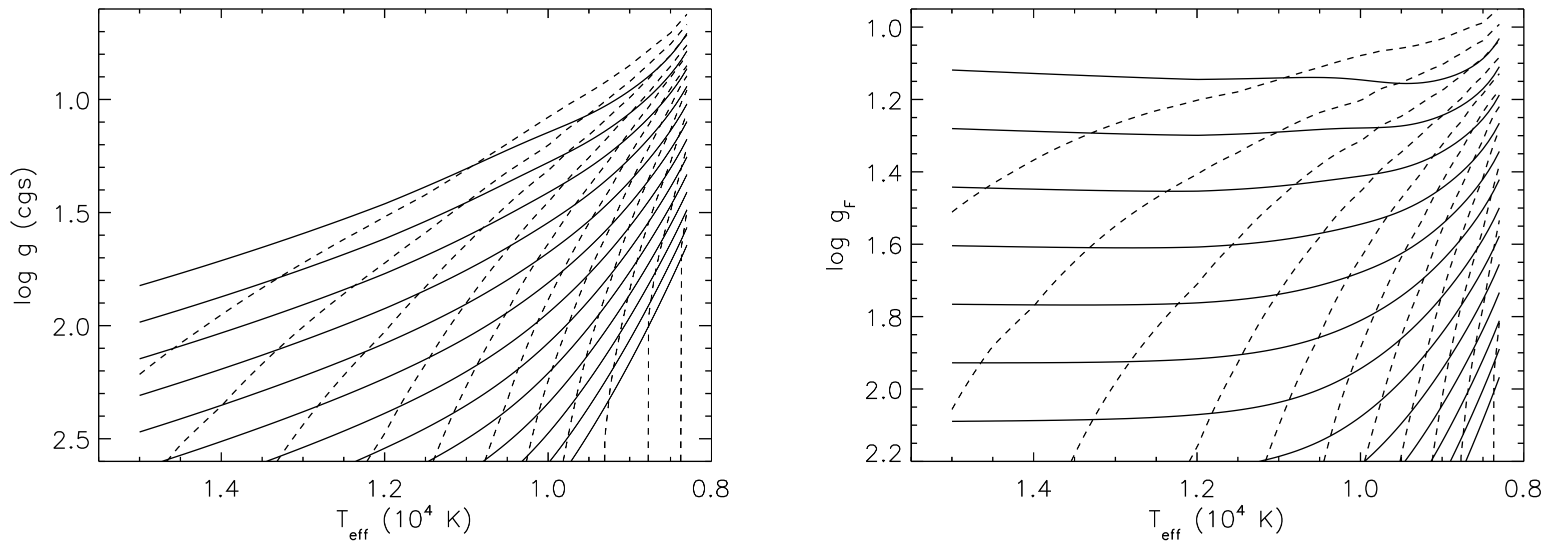

Figure 1. Left: Isocontours of Hδ equivalent widths (solid) and Balmer jump D_B (dashed) in the $(log\ g, log\ T_{eff})$ plane. Hδ isocontours start with 1 Å equivalent width and increase in steps of 0.5 Å. D_B isocontours start with 0.1 dex and increase by 0.1 dex. **Right:** Same as left but for the flux weighted gravity $log\ g_F$ instead of gravity $log\ g$. Note that this diagram is independent of metallicity, since both the strengths of Balmer lines and the Balmer jump depend only very weakly on metallicity.

Figure 5: from Kudritzki et al. (2008a)

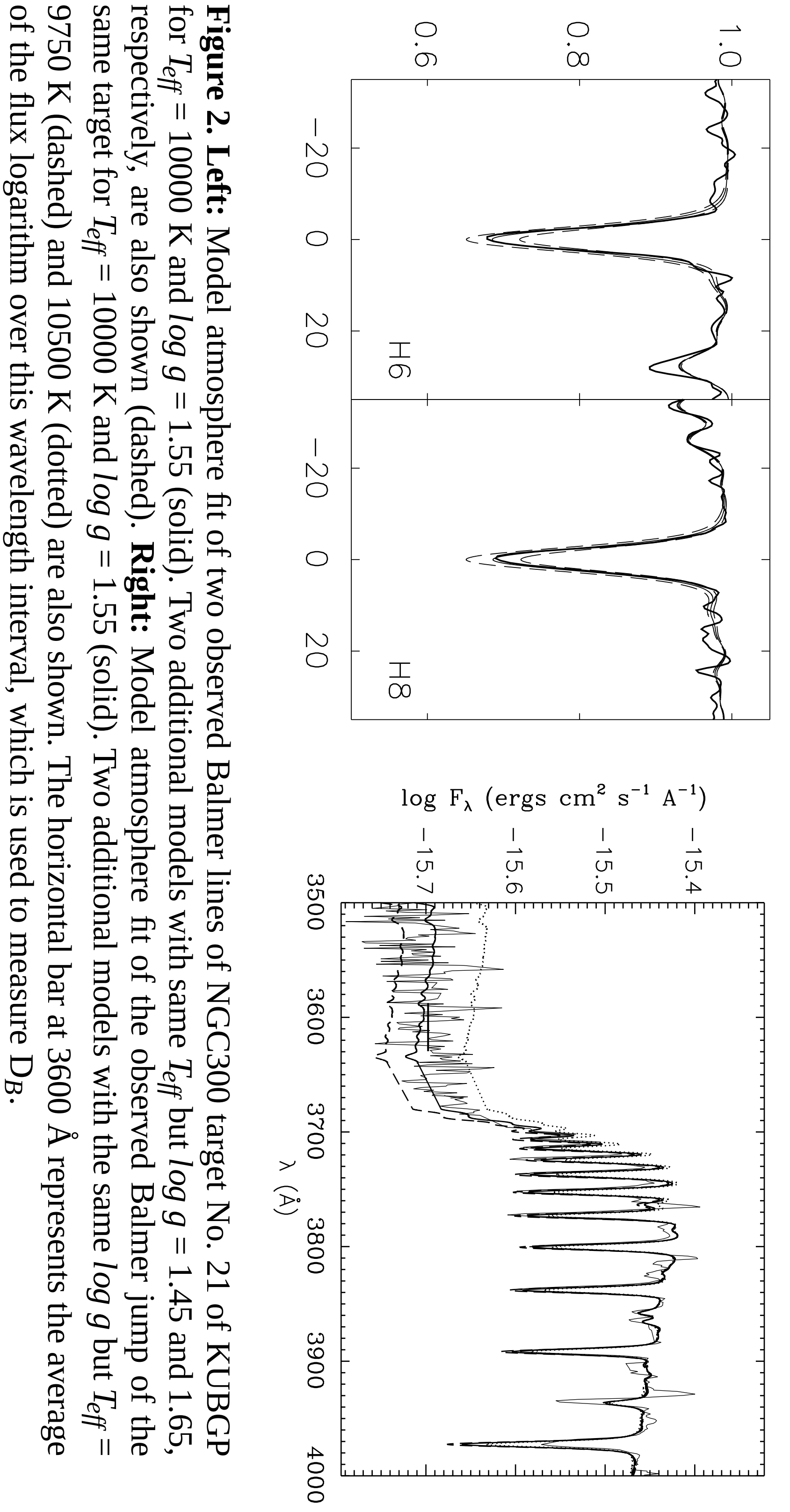

Figure 6: from Kudritzki et al. (2008a)

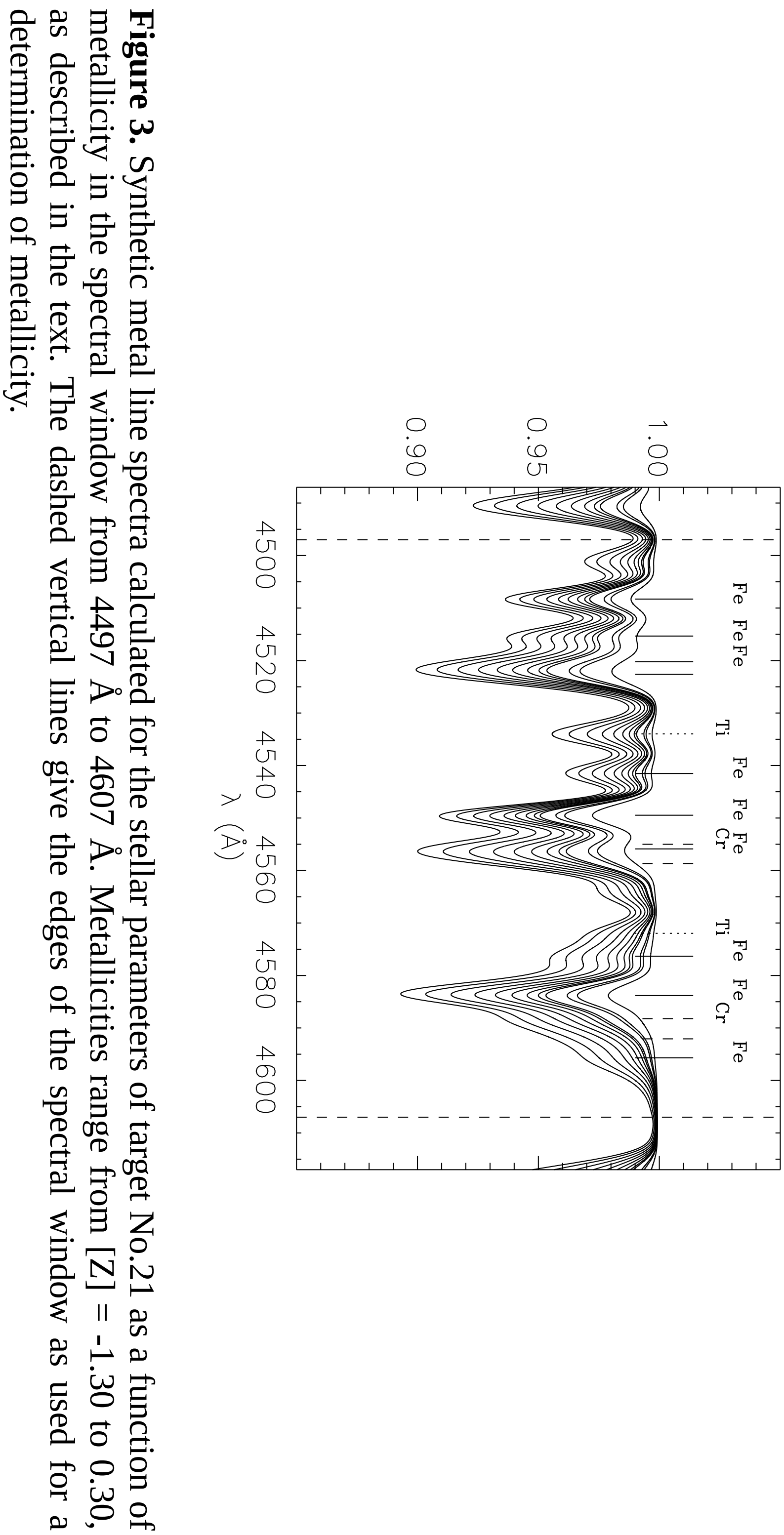

Figure 7: synthetic spectra vs metallicity from Kudritzki et al. (2008a)

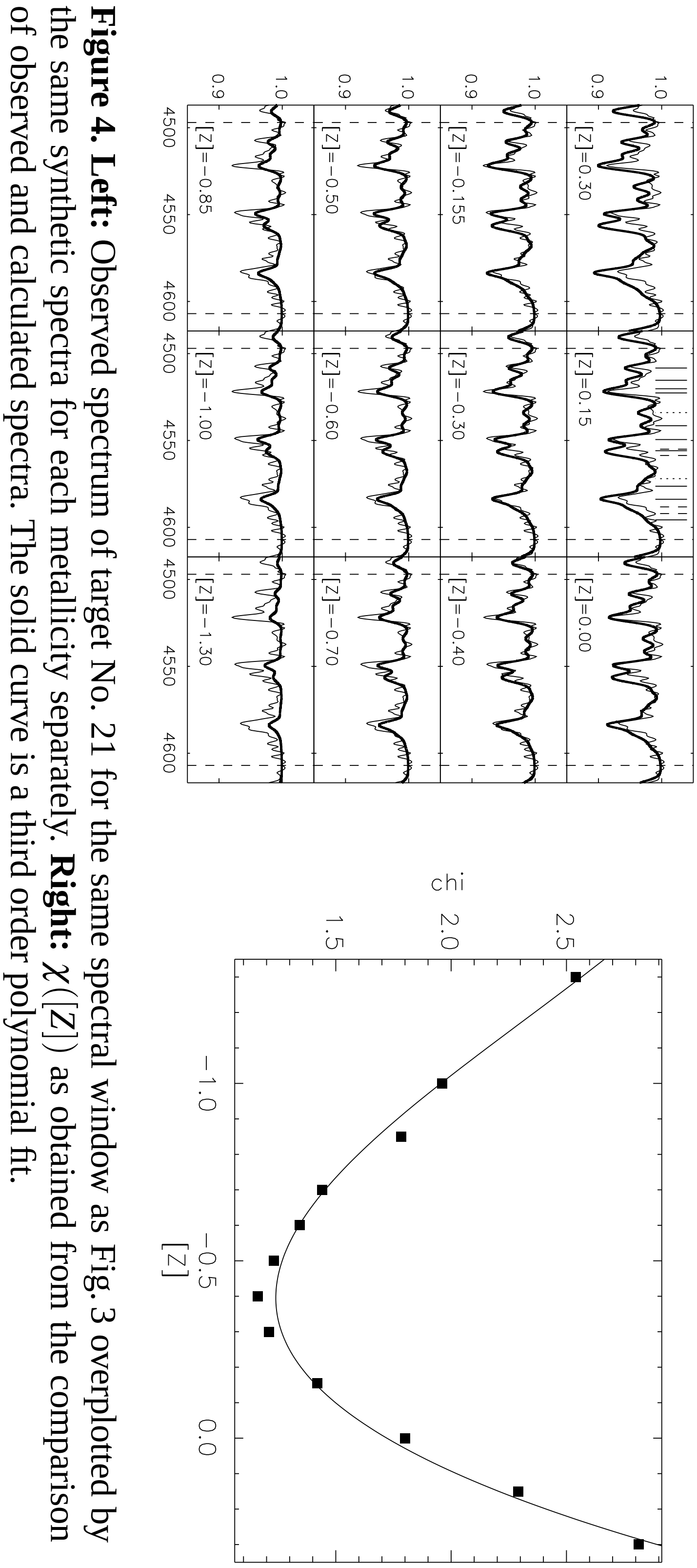

Figure 8: Metallicity estimation, from Kudritzki et al. (2008a)

Model atmospheres

Two kinds of *classical* (plane-parallel, hydrostatic and stationary) model atmospheres are typically applied in the contemporary literature for analyses of BA-SGs: line-blanketed LTE atmospheres and non-LTE H+He models (without line-blanketing) in radiative equilibrium. First, we discuss what effects these different physical assumptions have on the model stratification and on synthetic profiles of important diagnostic lines. We therefore include also an LTE H+He model without line-blanketing and additionally a grey stratification in the comparison for two limiting cases: the least and the most luminous supergiants of our sample, η Leo and HD 92207, of luminosity class (LC) Ib and Iae. The focus is on the *photospheric* line-formation depths, where the classical approximations are rather appropriate – the velocities in the plasma remain sub-sonic, the spatial extension of this region is small (only a few percent) compared to the stellar radius in most cases, and the BA-SGs photospheres retain their stability over long time scales, in contrast to their cooler progeny, the yellow supergiants, which are to be found in the instability strip of the Hertzsprung-Russell diagram, or the Luminous Blue Variables.

The non-LTE models are computed using the code TLUSTY (Hubeny & Lanz 1995), the LTE models are calculated with ATLAS9 (Kurucz 1993), in the version of M. Lemke, as obtained from the CCP7 software library, and with further modifications (Przybilla et al. 2001b) where necessary. Line blanketing is accounted for by using solar metallicity opacity distribution functions (ODFs) from Kurucz (1992). For the grey temperature structure, $T^4 = \frac{3}{4} T_{\rm eff}^4 [\tau + q(\tau)]$, exact Hopf parameters $q(\tau)$ (Mihalas 1978, p. 72) are used.

Figure 9: Details of model atmospheres used, from Przybilla et al. (2006)

References

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