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High Resolution Spectroscopy As a Tool for Luminosity Calibration

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Abstract. Recent results are reviewed for two methods of luminosity calibration based on high-resolution spectroscopy. The first relies on $T_{\rm eff}/\log g$ determinations from model-atmosphere analyses based on high-resolution spectra. This method is physically well founded but operationally demanding, and requires advance knowledge of stellar mass. The second, W-B, stems from the empirical relationship between luminosity and the width of chromospheric emission lines first established by Wilson and Bappu. Its physical basis is only partially understood, however, and the calibration depends on stellar metallicity and on the choice of lines.

Both $T_{\rm eff}/\log g$ and W-B easily distinguish cool dwarfs from cool giants. Generally reasonable agreement is found between distances derived from Hipparcos parallaxes and those inferred from the log g values derived for nearby dwarfs with relatively well-known Hipparcos parallaxes, $\sigma(\pi)/\pi < 0.2$. Constraining Hipparcos parallaxes star-by-star is not possible at present. Improvements are suggested for both approaches.

1. Comparing Hipparcos Parallaxes with those from $T_{\rm eff}/\log g$

Stellar distance may be inferred in ways other than the direct measurement of parallax. One means is by comparing the absolute brightness with the apparent brightness, correcting for extinction if necessary. The relationships defining stellar effective temperature $T_{\rm eff}$ and surface gravity log g are combined (e.g. eq. 1 of Allende Prieto et al. 1999) to show that parallax $\log \pi = 0.5 \log g - 2 \log T_{\rm eff} - 0.5 \log M - 0.2\,V - 0.2\,BC$ +constant, with M the stellar mass, V the observed visual magnitude corrected for extinction, and BC the bolometric correction.

The metal-poor stars of the old halo population offer an opportunity to apply this method, as their turnoff masses are assumed to be $0.8\,M_\odot$ by analogy with globular clusters. Allende Prieto et al. (1999) checked literature determinations of spectroscopic gravities for nearby F–K stars against those from Hipparcos parallaxes, finding disagreements for stars with metallicity less than one-tenth solar. However, Fulbright (2000) carried out new analyses for 169 stars of the old disk and halo population, the majority of which are metal-poor dwarfs. Good agreement was found between gravities derived spectroscopically and those deduced from Hipparcos parallaxes, after excluding all known binaries and those stars for which the uncertainty in the Hipparcos parallax was $\geq 20\%$ of its value. Since few if any metal-poor giants met this criterion, the comparison refers to dwarfs.

Uncertainties in determinations of $T_{\rm eff}$ and log g still preclude star-by-star constraints on Hipparcos parallaxes, except in favorable cases such as nearby binaries or stars whose angular diameters are measured. $T_{\rm eff}$ is often derived from photometric colors or the infrared flux method, but both approaches are sensitive to reddening and to the modeling of convection. For example, Alonso, Arribas, & Martinez-Roger (1996) applied the infrared flux method with reddening determined from Strömgren Hβ index or $V - K$ vs. $J - K$ colors, but unfortunately relied on models from Kurucz (1991 and private communication) in which convective overshoot distorts colors (Castelli, Gratton, & Kurucz 1997). Determining $T_{\rm eff}$ from Balmer-line profiles is reddening-independent but still very model-dependent (Magain 1984; Fuhrmann, Axer, & Gehren 1994). $T_{\rm eff}$ methods that rely on the excitation equilibrium of Fe I (e.g. Fulbright 2000) are reddening-independent and model-independent if lines are weak, but susceptible to systematic errors in laboratory measurements of gf-values (Blackwell et al. 1982) as well as to possible departures from local thermodynamic equilibrium (Thévenin & Idiart 1999). These two sources of uncertainty also plague log g determinations based on ionization equilibria, as do $T_{\rm eff}$ uncertainties as well.

Possibilities for improving the situation start with the use of Castelli et al. (1997) models in which convective overshoot has been turned off. These are available from the Kurucz Web site at http://cfaku5.harvard.edu. Peterson, Dorman, & Rood (2000) have shown that when these models are used, a simultaneous analysis of mid-ultraviolet and echelle spectra gives $T_{\rm eff}$ to ± 50 K for nearby main-sequence turnoff stars of metallicity one-tenth solar and below, with the mid-UV flux distribution and the Hα profile both matched. Ultimately, 3D models such as those of Asplund (in JD8, this volume) might lead to significant improvements.

Further progress could also be expected by basing gravity determinations on the profiles of strong lines. Fuhrmann et al. (1997) have advocated the use of Mg I lines; another possibility is Fe I lines for which damping constants have been calculated from first principles by Anstee & O'Mara (1995) and Barklem & O'Mara (1997), since the iron abundance can be found from weaker lines. For extremely metal-poor stars, the strongest features such as the Ca II near-infrared triplet might prove useful. At present, the use of the profiles of strong metal lines can readily discern dwarfs from giants among cool stars at any distance, as evidenced by the use of such lines as luminosity criteria in spectral classification.

2. Comparing Hipparcos Parallaxes with those from the Wilson-Bappu Effect

Wilson & Bappu (1957) noted that the breadths of the Ca II H and K emission line cores in G, K, and M stars are related to stellar absolute magnitude M_V. Although it is known that the emission arises in the lower chromosphere, there is still no comprehensive theoretical explanation for this phenomenon. Similar relations are found for other strong resonance lines, notably the Mg II near-UV doublet at 2800 Å and Lyman α at 1216 Å, but with a different numerical constant in each case. Scoville & Mena-Werth (1998) recalibrated the Mg II breadths for 94 stars with IUE spectra, while Elgarøy, Engvold, & Lund (1999) extended this using Hipparcos parallaxes. They found that the W-B breadth

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predicted M_V to about one magnitude over a range of 15 magnitudes for stars of types G, K, and M. They saw signs of deviations among the more active stars, and a tendency for widths to be narrower at lower metallicities among the limited metallicity range of their sample. Thus the W-B method easily distinguishes G – M giants from dwarfs, and might do better if deviations were understood.

Some deviant behavior is seen on the Sun. The profile breadth varies with position across the solar surface, and in time with the solar magnetic cycle (Pasquini 1992). On other stars, unusually broad widths are seen among active stars (Elgarøy, Engvold, & Joräs 1997) and among those with high luminosities (Wallerstein, Machado-Pelaez, & Gonzalez 1999). Unusually narrow widths are found among metal-poor stars (Dupree & Smith 1995).

Regardless of metallicity, all dwarfs show a double-peaked Mg II profile, with the blue peak at least as strong as the red (Peterson & Schrijver 1997). At higher luminosities the blue peak is gradually suppressed (Ayres et al. 1995), suggestive of outflow in the most luminous metal-poor stars (Dupree et al. 1994). Absorption from the interstellar medium is seen in all high-resolution Mg II observations (e.g. Peterson & Schrijver 1997); in Lyman α observations, it obliterates the central 0.3 Å of the profile of even the nearest stars (e.g. Linsky & Wood 1996).

One empirical path towards improved constraints is to compare Mg II widths in Hyades stars versus those of the nearby system α Cen A and α Cen B. Masses of the latter are established from their orbit, independent of Hipparcos, by Pourbaix, Neuforge-Verheecke, & Noels (1999), using all visual and spectroscopic observations. $T_{\rm eff}$, log g, and [Fe/H] have been determined recently for each member of the pair by Neuforge-Verheecke & Magain (1997), confirming their above-solar metallicity and the evolved status of α Cen A. The Hyades metallicity is very similar (Boesgaard & Friel 1990). In principle, one might compare the emission breadths of single Hyades stars of various luminosities, interpolating between the widths observed for α Cen A and α Cen B to establish a luminosity on the scale of that system.

To this end, we have examined existing Mg II spectra. Very high quality spectra were obtained for α Cen A and α Cen B with the Hubble Space Telescope (HST) echelle spectrographs by Linsky & Wood (1996) and Linsky et al. (2000). Böhm-Vitense has obtained HST spectra at lower S/N for a dozen Hyades F stars. These reveal a major complication: rotation, even at a low level, broadens the emission excessively in most cases, even in slow but finite rotators such as HD 27808 ($v \sin i = 6\,{\rm km\,s^{-1}}$). Coupled with the moderate S/N of these spectra and the variability in the interstellar absorption from Hyad to Hyad, it is not yet possible to pinpoint the M_V values of the Hyades in this fashion.

With various improvements, such a comparison might be feasible. If the intrinsic profile at zero rotation could be approximated, it could easily be broadened to emulate arbitrary $v \sin i$. The role of activity in broadening the intrinsic profile could be calibrated using X-ray or coronal indicators. More importantly, better spectra could be taken for early G through K Hyades stars, to overlap α Cen A and α Cen B in $T_{\rm eff}$. Several Hyades stars in this temperature regime are extremely slow rotators (e.g. Cayrel et al. 1984; Soderblom et al. 1990). Widths for half-dozen or more such Hyades stars should reveal both the internal and the external validity of the Hipparcos parallaxes.

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