EMPIRICAL SURFACE GRAVITIES

(from spectra and from binaries)

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Abstract. The surface gravity of a star (log g) is a fundamental parameter in models of stellar atmospheres. Given suitable spectra, log g can be determined from such models with an accuracy of 0.1dex, at best. Detached eclipsing binary stars can provide values of log g an order of magnitude more accurate than this, though for a more limited range of stars. Naturally, less accurate surface gravities can be obtained for a wider range of eclipsing binary stars.

These facts are well known, so in this short review I will outline the types of stars to which the two methods have be usefully applied and might be applied in the near future. This naturally leads to the question of where the two ranges overlap and the comparison of results from the two methods. Techniques for allowing this comparison to made directly will be described. Surface gravities derived from winds in hot stars and (indirectly) from gravitational redshifts in white dwarf stars will also be covered briefly.

1. Introduction

The surface gravity of a star (log g) is a fundamental parameter in models of stellar atmospheres and arises naturally from the masses and radii determined for stars in eclipsing binary systems. This short review will summarise the reliability and accuracy of the two methods and describe methods for directly comparing the results.

2. Overview

The determination of log g for a star from its spectrum has been applied to stars of almost every type with quoted accuracies $\sim$ 0.1dex being typical. Since this method relies on fitting a model to the observed data further

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uncertainty is introduced i.e. values of log g determined from spectra are prone to systematic errors.

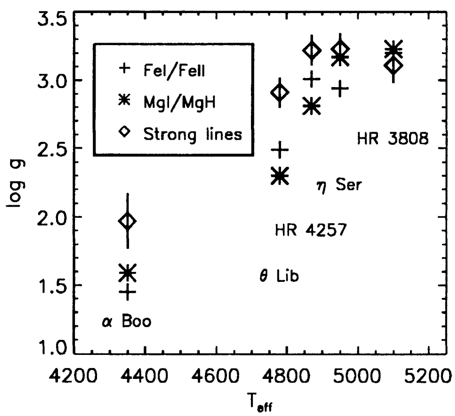
Eclipsing binary stars (EBS) yield masses and radii for the component stars from the analysis of the lightcurve and the spectroscopic orbit. With high quality data for stars in systems uncomplicated by proximity effects, log g can be reliably determined to $\sim$ 0.01dex. Provided care is taken to do the analysis properly, these values are free from systematic errors. This method is, of course, limited to those stars found to be EBS, although the method can be applied to a wider range of stars at the expense of lower accuracy.

The direct comparison of values of log g determined by these two methods is now feasible and desirable.

3. Surface gravities from spectra

A complete catalogue of log g determinations is not feasible in a short review and so I will simply summarise two recent reviews of the modeling of spectra which capture the flavour of the work that has been done.

Figure 1. Surface gravities of 5 cool giants



3.1. SPECTROSCOPY OF COOL STARS

Gustafsson(1989) has reviewed the chemical analysis of cool stars. The determination of log g is fundamental to this process and so Gustafsson has covered this topic in some detail. Three techniques are described: ionisation equilibria, dissociation equilibria and damping wings of strong lines. Since

Gustafsson's review all three methods have been applied to the 5 cool giant stars as shown in Fig. 1. The error bars shown for the data of Edvardsson are the result of a thorough discussion of the uncertainties involved and similar errors ($\sim$ 0.1dex) are quoted for the other log g determinations. Although the methods tend to agree, differences of up to 0.5dex are evident. There is further uncertainty in these log g determinations due to correlations between log g and $T_{\rm eff}$ (though this is less of a problem for the "strong line" method). These differences are presumably due to deficiencies in the modelling of cool stellar atmospheres e.g. convection stubbornly defies a simple treatment. The result is that log g for cool giant stars is often determined from an adopted absolute magnitude and a mass predicted from evolutionary tracks, which yields accuracies $\sim$ 0.5dex. Systematic errors in these determinations due to composition and mass variations are difficult to quantify.

3.2. SPECTROSCOPY OF HOT STARS

The atmospheres of hot stars are relatively simple when compared to those of cool stars, or at least, they are sufficiently uncomplicated that our understanding of the relevant physics is adequate for *quantitative spectroscopy of hot star* (QSHS) to be feasible. The concept of QSHS is reviewed by Kudritzki & Hummer and refers to "the systematic acquisition and analysis of accurate spectroscopic data ... in order to determine accurate values of the stellar parameters ...". Stellar winds are commonplace among hot stars and the modelling of spectral features due to the wind provides valuable data that complements the data derived from the photospheric features. In particular, log g can be determined independently using both methods with comparable accuracy. This is precisely what has been done by Herrero *et al.*(1992) for 25 luminous galactic OB stars. Fig. 2. shows the values of log g derived from their data for the 21 stars to which the method is applicable. The mean difference between the methods is 0.07 ± 0.10, a very encouraging result.

4. Eclipsing binary stars

Very accurate values of log g($\pm \lesssim 0.02$) can be determined in the case of detached EBS. Andersen's review (1991) of radii and masses for normal stars lists 45 binaries that fall into this category. They cover the majority of the main sequence although there are very few systems at the extremity of the mass range. Away from the main sequence, only two normal giant stars are listed (AI Phe and TZ For). Work continues to extend the range of normal stars for which accurate parameters are available. These and other notable EBS are:

Figure 2. Surface gravities for Hot stars.

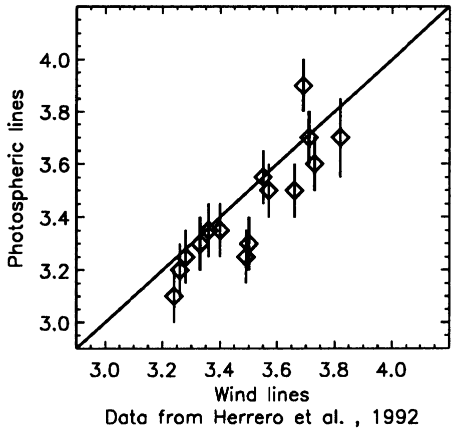


TABLE 1. Surface gravities for giants in ζ Aurigae binaries

Name	Sp. Type	log g
ζ Aur	K4Ib + B5V	0.86 ± 0.02
22 Vul	G2Ib + B8V	1.40 ± 0.17
τ Per	G8IIIa + AV	2.41 ± 0.07
HR 6902	G9IIb + B8-9V	1.99 ± 0.04
31 Cyg	K4Ib + B3-4V	0.92 ± 0.10

CM Dra A remarkably useful EBS comprising two old M dwarfs (Metcalfe *et al.*, 1995). The weak chromospheric activity should enable more accurate parameters to be determined than for YY Gem, the only other known M dwarf EBS. This star is currently under intensive study.

V643 Ori This pair of eclipsing giant stars cannot be the product of single star evolution but is nevertheless an interesting system for which accurate parameters will be published soon(ish)

LZ Cen, V346 Cen, GL Car Several new, massive ($> 10 M_\odot$) eclipsing binaries have been identified in recent years. Lightcurves have been secured for the three systems listed and the analysis of spectra to determine spectroscopic orbits continues. The Magellanic clouds are a fruitful source of high mass binaries although more effort is required to derive accurate parameters and so results may be slow to appear.

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HR 7940 Clayton(1996) has observed primary and secondary eclipses in this reddened B2III star. Accurate parameters of this rare system will be interesting but may take some time given that the period is 99.76days

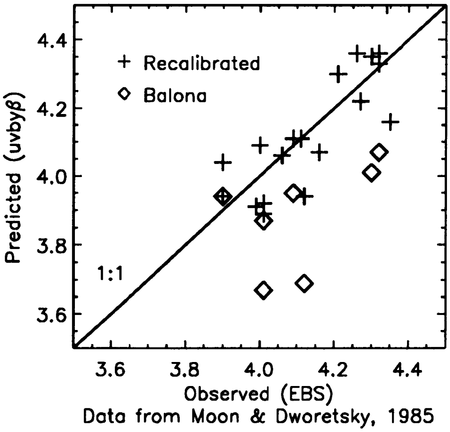
ζ Aurigae systems Several of these G/K bright giant + BV eclipsing binaries have been analysed by Griffin and others. Their results for log g summarised in Table 1.

Detached white dwarf binaries The work of Marsh *et al.*(1995) in which he finds 7 out of 9 low-mass DA white dwarfs to be short-period binaries has led to a concerted effort to find more of these systems. Until we are lucky enough to find an eclipsing system, the gravitational redshift can aid in the determination of log g (since it determines the ratio M/R). E.g. Reid(1996) has measured gravitational redshifts in 53 WD systems in clusters and in wide binaries. In systems with a measured parallax, $T_{\rm eff}$ leads to an estimate of the radius and so log g can be determined to $\sim$ 0.1dex

5. Direct Comparison of the methods

The reasons for making a direct comparison between values of log g derived from EBS and spectra are nicely illustrated by Fig. 3 which is based on the work of Moon & Dworetsky(1985). The diamonds show the log g values predicted by the $uvby\beta$–log g calibration of Balona(1984) compared to the observed values in EBSs with similar components. The mean difference in log g is 0.22 ± 0.15dex, which again shows that log g values from "spectra" show an intrinsic accuracy $\sim$ 0.1dex but that this may hide systematic errors. Moon & Dworetsky have used the observed log g of these EBSs to apply corrections to the $uvby\beta$–(log g,$T_{\rm eff}$) calibration of Relyea & Kurucz(1978). The success of this approach is evident from the agreement between the observed and predicted values (crosses) for which the mean difference is -0.01 ± 0.10dex. In general, for EBS with dissimilar components, some method is required to separate the combined spectra of the components so that they can be analysed as though they were singled stars. Three such methods exist, all of which take advantage of the varying Doppler shift to distinguish the two components. Bagnuolo & Gies(1991) have used their "Doppler tomography" technique to establish spectral types for the binary O-star AO Cas and others. Simon *et al.*(1994) have applied their "Disentangling" method to the massive EBS Y Cyg. Their analysis of the resulting spectra yields surface gravities for the two components of 4.16 ± 0.10 and 4.18 ± 0.10, in excellent agreement with the actual values of 4.140 ± 0.012 and 4.149 ± 0.012. Finally, Hadrava(1995) has developed a method based on Fourier transforms, although no results with this method

Figure 3. Surface gravities of EBS from *uvbyβ* photometry.



have been published yet.

6. Conclusion

Now that techniques for the direct comparison of log g values of EBS with those predicted from their spectra are available, the comparison should be made for the increasing range of EBS for which accurate log g values are available. This has already been shown to be an effective technique for revealing any systematic errors that may be present.

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