ACCURACY OF THE HR DIAGRAM AND RELATED PARAMETERS

Chairperson and Editor: **M. GERBALDI**

https://doi.org/10.1017/S1539299600011527 Published online by Cambridge University Press

THE EFFECTIVE TEMPERATURE DETERMINATION

ROGER CAYREL
Observatoire de Paris, Departement d'Astrophysique Stellaire et Galactique
61, av. de l'Observatoire 75014 Paris,France
E-mail: Cayrel@obspm.fr

1. Introduction

The content of my oral contribution has been reduced here to a guide to the recent litterature on the subject.

2. Use of the basic Method

The effective temperature of a star can be obtained directly by measuring the total flux received on earth from it, and its angular diameter.In principle interferometric methods could determine both the limb-darkening law of the stellar disk and the angular diameter of the disk. In practice, in order to obtain a decent accuracy on the angular diameter, interferometric methods have so far borrowed the limb-darkening law from stellar atmosphere theory, in order to concentrate all the observational information on a single parameter. The total number of stellar diameters and effective temperatures obtained by this basic method remains very small (about 30 stars) and concerns exclusively giant or subgiant stars. The reader is invited to look at the following references and those therein (Di Benedetto 1993, Mozurkewich et al. 1991, Alonso et al. 1994). Smalley and Dworetsky (A&A in press) have reinvestigated the old Code et al. (1976) calibration with more recent spatial UV data, for B,A, and F stars, and have found no significant changes. The accuracy of the basic method is at the best of the order of 1.5 % , and there is a deep need for more data, and for doubling the current accuracy. Actually there is a strong effort for developping interferometry both from the ground (ESO VLTI, USNO astrometric interferometer) and from space (OSI project, Colavita et al. 1993; GAIA project at ESA). So there is hope for a not to far future.

I. Appenzeller (ed.), Highlights of Astronomy, Vol. 10, 395–398.

3. The Infrared Flux Method (IRFM)

The IRFM has been defined by Blackwell and Shallis in 1977. It has been revised by Blackwell, Lynas-Grey and Petford in 1991. It has been applied by a considerable number of other authors, and is considered by most people as the second best method for determining effective temperatures. The general idea is that the angular diameter $2R/d$ can be derived from :

$$f_\nu = F_\nu (R/d)^2$$

where the monochromatic fluxes at the earth (f_ν) and at the surface of the star (F_ν) are taken at an infrared frequency,*where F_ν is much less sensitive to the exact value of T_{eff} than F.* Actually, in the infrared, F_ν is practically proportional to T_{eff} :

$$F_\nu = a(T_{eff}, g, [Fe/H]).T_{eff}$$

and T_{eff} is derived from:

$$\sigma T^3_{eff} = (f/f_\nu)a(T_{eff}, g, [Fe/H])$$

where f and f_ν are observed, and a computed from a grid of model atmospheres, with no appreciable dependence of a on T_{eff}. The authors have found that using improved opacities of the ion H^- (John 1988) changes the derived effective temperatures by as much as 3% at the cool end.This is one of the two weak points of the IRFM: it depends upon the models used, and also of the absolute calibration of stellar fluxes, still subject to uncertainties. A spanish group (Alonso, Arribas and Martinez Roger) has undertaken a large body of redetermination of effective temperatures by this method for over 500 stars,to be published soon (Alonso's thesis).

4. Effective Temperature from Photometric Indices.

Fundamental methods are limited to the two already exposed. However one is very frequently faced with the problem of determining the effective temperature of a star, for performing for example an abundance analysis , with whatever one has got, most of the time one or several photometric indices. For stars later than F the king of the photometric indices, for which the error on the calibration is less than 150 K, is the Johnson index $V - K$.

V-K index. The reference Blackwell et al. 1991 contains a recent recalibration of T_{eff} versus $V - K$ from 3800 K to 8500 K. The cool end is in good agreement with the older determination by Ridgeway et al.1980 by measurements of angular diameters by occultations, and in reasonable

https://doi.org/10.1017/S1539299600011527 Published online by Cambridge University Press

agreement with the calibration of Gustafsson 1989, and Arribas and Martinez Roger 1989, or the more recent one of Di Benedetto 1993. The $V-K$ index is the only one for which differences between various calibrations does not exceed 120 K and are most of the time not more than 60 K. Thanks to its large baseline it is a very robust index to be preferred when available.

UBV photometry is the worse case for determining effective temperatures. If possible one should use V-I instead of B-V to determine effective temperatures. The calibration of Bessel 1979 is still fairly good but an updated calibration can be obtained by anonymous ftp from the machine merlin.anu.edu.au on the file /pub/wood/ubvrijkl.dat. The classical calibration by Saxner and Hammarbäck 1985 is still a useful reference, but must not be applied to very metal-poor stars, being calibrated by stars not more metal-poor than -1 dex. Conversely, Magain 1987 calibration must be applied only to stars more metal-poor than -1.2. Recently King 1994 has claimed that the Magain 1987 scale is too cool by 150 K, but this is not much above the uncertainties involved in temperature determinations from *UBV* photometry. Carney 1983 temperature scale, with a correction for metallicity from the $\delta(U-B)_{0.6}$ excess is still a widely used reference. This scale is likely too cool for stars which are not metal poor (see Carney et al. 1994).

Strömgren photometry is one of the best calibrated. One should consult recent references as Edvardsson et al. 1993 for F and early G stars, Napiwotzki et al. 1993 for B,A,F stars, Castelli 1991 for B stars, Smalley and Dworetsky (A&A under press) for B,A,F and Am stars. For a wide range in $(b-y)$ it is necessary to use older Olsen 1984 calibration.

Geneva photometry represents now an important set of data. A recent thesis by Cramer (see Cramer and Maeder 1979, Cramer 1984) takes care of the calibration for hot stars. For cool stars there is no published calibration and the best recipe remains "sending an E-mail to Grenon". Hauck and North 1993 have considered the case of Am and Ap stars.

5. Effective Temperature from Balmer Lines.

A very important development has occured in effective temperature derivation from Balmer lines. Axer et al. et al. 1993 and Fuhrmann 1993 (thesis) have shown the importance of the choice of the mixing-length parameter for the determination of effective temperatures from the strength of the wings of the Balmer lines. They conclude that a low value of $\alpha = l/H_p$ is required to get a correct effective temperature from all Balmer line, H_β and $H\gamma$ being more affected by this choice than H_α. The recommended value is $\alpha = 0.5$ (for Kurucz or Gehren's models) and slightly above for the Bell-Gustafsson models . The phenomenon is stronger in cool subdwarfs, where one "sees" deeper in the convective zone.

6. Concluding Remarks

At the present time a set of stars with accurate effective temperatures, derived from fundamental or quasi-fundamental methods, covering the HR diagramme, including the range of metallicities found in the Galaxy, is simply not available. It is an urgent task to dispose of such a set , preferably made of stars near the equatorial plane , to have easy access from both hemispheres. Once such a set has been established, the calibration of all temperature indicators (photometric indices , Balmer lines, etc)... will become possible, and easy.

References

Alonso A., Arribas S., Martinez-Roger C. 1994, A&A **282**, 684
Arribas S., Martinez-Roger C. 1989 A&A **215**, 305
Axer M., Fuhrmann K., Gehren T., 1994 A&A **271**,451
Bell R.A., Gustafsson B. 1989, MNRAS **236**,653 Bessel M.S.,1979 PASP **91**, 589
Blackwell D., Shallis M.J. 1977, MNRAS **180**,177
Blackwell D.E., Lynas-Grey A.F., Petford A.D. 1991 A&A **2545**,567
Code A.D., Davis J., Bless R.C., Hanbury Brown R.1976, ApJ **203**,417
Colavita M.M., Shao M., Rayman N.D. 1993 Appl.Optics **32**, 1789
Di Benetto G.P., 1993 A&A**270**,315
Bell R.A., Gustafsson B. 1989 MNRAS **236**, 653
Carney B.W.1983 AJ **88**, 623
Carney B.W., Latham D.W., Laird J.B., Aguilar L.A. 1994 AJ **107**, 2240
Castelli F., 1991 A&A **251**, 106
Cramer N., 1984 A&A, **132**, 283
Cramer N., Maeder A., 1979 A&A **78**, 305
Edvardsson B., Andersen J., Gustafsson B., Lambert D.L., Nissen P.E., Tomkin J. A&A **275**, 101
Fuhrmann K.1993 Thesis,*Temperatur und Elementhaäufigkeiten von F- und G-Sternen*,München, Germany
Hauck B., North P. 1993 A&A **269**, 403
John T.L., 1988 A&A **193**,189
King J.R. 1994 AJ **106**, 1206
Magain P. 1987, A&A **181** , 323
Mozurkewich D., Johnston K.J., Simon R.S., Bowers P.F., Gaume R., Hutter D.J. Colavita M.M., Shao M., Pan X.P. 1991 AJ, **101**,2207
Napiwotski R., Schönberner D.,Wenske V. 1991, A&A **268**,653.
Olsen E.H., 1984, A&A Suppl. **57**, 443
Ridgway S.T., Joyce R.R., White N.M., Wing R.F. 1980, ApJ **135**,126
Saxner M., Hammarbäck G., 1985, **151**, 372

(Discussion after the paper by Gomez and Turon)