EFFECTIVE TEMPERATURE DETERMINATION OF ECLIPSING BINARIES

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ABSTRACT

Effective temperatures and distances of eclipsing binaries computed through Hipparcos trigonometric parallaxes were compared with the photometric determinations. The former were based on the radius, the apparent visual magnitude and the bolometric correction of the star, whereas the latter were obtained from standard calibrations using Strömgren or Johnson colour indices.

The study was performed for a sample of 15 detached eclipsing binaries that can be regarded as single stars, and 9 RS CVn-type binaries and 11 Algol-type binaries, with a relative error in the Hipparcos parallax less than 20 per cent. The stars in the sample came from 1982 proposal number 177 and 1992 internal proposal number 84. The comparison of effective temperatures for the detached systems was used to test the standard photometric calibrations applied to isolated stars and the validity of the same calibrations for stars with some level of interaction.

Key words: Effective temperatures; Eclipsing binaries: detached, RS CVn-type, Algol-type.

1. INTRODUCTION

Eclipsing binaries with double-lined spectra and good quality light curves provide the most complete database for the study of stellar structure and evolution and the only accurate determination of masses and radii.

The comparison of absolute dimensions with theoretical models requires additional information about the effective temperature of the stars or their luminosity. The level of precision nowadays available in masses and radii (below 1 per cent), is not matched by the temperatures, which are determined through colour indices and standard calibrations. The only independent test of the equations adopted is the direct determination of stellar luminosities by means of trigonometric distances.

The problem increases its importance for eclipsing binaries with some level of interaction, such as Algols, with mass transfer between the components, or RS CVn-like active binaries, where dynamo processes enhanced by synchronized rotation produce a variety of solar-type effects like spots, plages or coronal emission. For these systems, the validity of photometric calibrations for 'normal' stars to determine temperatures is uncertain.

2. $T_{\rm eff}$ FROM PHOTOMETRIC CALIBRATIONS

The effective temperature of a star is frequently obtained by means of photometric calibrations, which take advantage of the correlation between certain colour indices and the temperature. Taking into account that the eclipsing binaries in our sample were mainly observed in Johnson and Strömgren photometric systems, we used the following calibrations:

- Moon & Dworetsky (1985) photometric grids using $c_\circ$ and β Strömgren indices;
- Popper's (1980) single-parameter calibration using $(B-V)_\circ$, $(V-R)_\circ$ or $(b-y)_\circ$.

3. $T_{\rm eff}$ FROM HIPPARCOS PARALLAX

Following the diagram presented in Figure 1, the effective temperature ($T_{\rm eff}$) of a star can be computed from its parallax, its apparent visual magnitude, its radius, the interstellar absorption and a bolometric correction by means of the expression:

$$T_{\rm eff} = T_\odot \left(10\pi \frac{R}{R_\odot}\right)^{-1/2} 10^{-0.1(V_\circ + BC - M_{\rm bol\odot})} \quad (1)$$

where π is the parallax in arcsec, $R/R_\odot$ is the radius of the star in solar units, $V_\circ$ is the absorption-free visual magnitude ($V_\circ = V - A_{\rm v}$), BC is the bolometric correction and $T_{\rm eff\odot}$ and $M_{\rm bol\odot}$ are the solar effective temperature and bolometric magnitude, respectively.

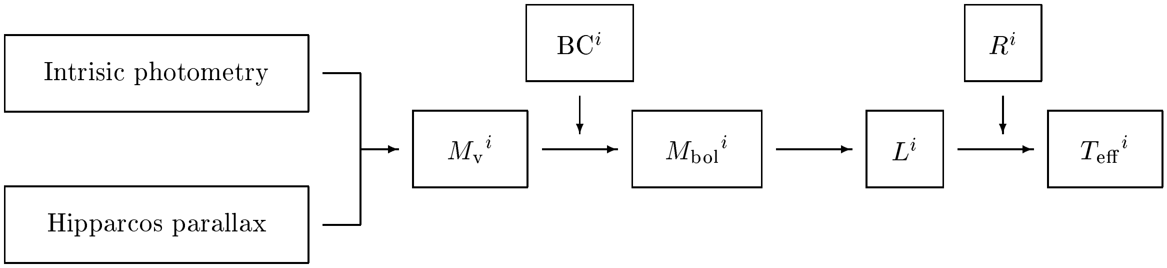

Figure 1. The procedure used in this study for the determination of effective temperature from the Hipparcos parallax, the bolometric correction and the radius of the star.

The uncertainty of the temperature determination from the parallax can be estimated by simple propagation of the errors associated with the parameters of Equation 1, and we obtain:

$$\left(\frac{\Delta T_{\rm eff}}{T_{\rm eff}}\right)_\pi \simeq 0.5\,\frac{\Delta\pi}{\pi} \qquad (\leq 10\%\ \text{if}\ \frac{\Delta\pi}{\pi} \leq 20\%)$$
$$\left(\frac{\Delta T_{\rm eff}}{T_{\rm eff}}\right)_R \simeq 0.5\,\frac{\Delta R}{R} \qquad (\sim 1\%)$$
$$\left(\frac{\Delta T_{\rm eff}}{T_{\rm eff}}\right)_{V_\circ} \simeq 0.1\ \ln 10\ \Delta V_\circ \approx 0.23\ \Delta V_\circ \qquad (\sim 0.4\%)$$
$$\left(\frac{\Delta T_{\rm eff}}{T_{\rm eff}}\right)_{\rm BC} \simeq 0.1\ \ln 10\ \Delta{\rm BC} \approx 0.23\ \Delta{\rm BC} \qquad (\sim 4\text{-}5\%)$$

The rough estimation of the errors on the right of the expressions come from adopting 2 per cent, 0.02 mag and 0.2 mag as uncertainties of the values of R, $V_\circ$ and BC, respectively. As seen in Equation 1, in order to keep the uncertainty of the temperature determination below 10 per cent, we restricted our study to those systems with a relative error in the Hipparcos parallax less than 20 per cent.

Several BC calibrations were considered: Code et al. (1976), Popper (1980), Habets & Heintze (1981), Schmidt-Kaler (1982), Malagnini et al. 1986 and Flower (1996). The mean differences between them for the detached eclipsing binaries in our sample range from 0.01 mag to 0.14 mag (meaning a maximum effect on the temperature of 3 per cent), except for the calibration of Habets & Heintze 1981, which shows strong systematic effects with a mean difference of 0.43 mag. Excluding the latter, our result reflects that there are only B-G-type stars in the sample, covering a temperature range in which the discrepancies between different BC calibrations are small. Flower's (1996) calibration was finally adopted, since it was the most recent one among those considered in the comparison. The same calibration was also adopted for the RS CVn-type and the Algol-type eclipsing binaries.

4. DETACHED SYSTEMS

We selected a sample of well-studied detached double-lined eclipsing binary stars, with accurate determination of their radii (1–2 per cent), based on the systems listed in Andersen's (1991) critical review. A similar sample was used to derive corrections to the photometric surface gravities in Jordi et al. (1997) and in the construction of biparametric calibrations

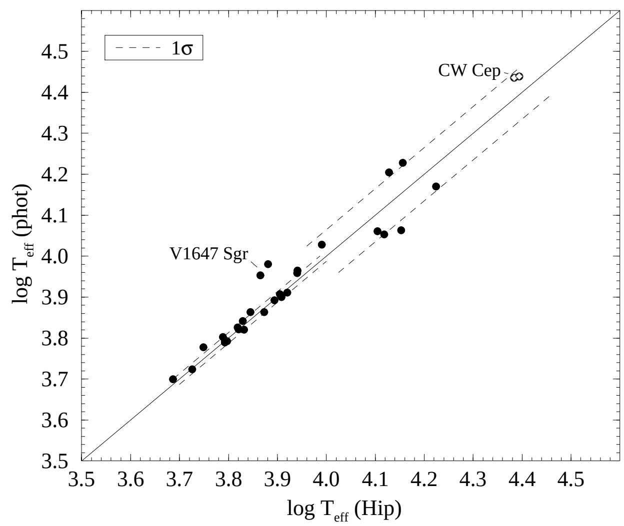

Figure 2. Hipparcos versus photometric determinations of effective temperature for the detached systems. The dashed lines are 1σ intervals for two different temperature ranges. Two systems mentioned in the text are highlighted.

to derive masses, radii and surface gravities in Ribas et al. (1997) with good results.

The photometric $T_{\rm eff}$ was computed from $c_\circ$ and β indices for most of the systems, but for a few systems without Strömgren photometry it was obtained from $(B-V)_\circ$.

Although we only considered those systems with $\Delta\pi/\pi < 20$ per cent, one additional system with larger relative error, CW Cep, was added, since its membership to Cepheus OB3 association (Clausen & Giménez 1991) allowed us to adopt its distance. Despite the large error of the Hipparcos parallax (70 per cent) the agreement with the distance to the association turned out to be very good.

If the errors in the parallax and in the remaining quantities are taken into account, the photometric and Hipparcos temperatures are compatible for all systems but one (V1647 Sgr), as shown in Figure 2.

V1647 Sgr is an apparently normal A-type eclipsing binary, but with a bright third component located at only 7.5 arcsec (the Hipparcos 'target' included both components). They appear to be a physical

Table 1. Statistics of the difference between the Hipparcos parallax-based and the photometric determination of effective temperatures for the detached systems. Two different $T_{\rm eff}$ intervals were considered. n is the number of stars in each subsample. V1647 Sgr was not considered.

	$T_{\rm eff}$(phot) $\leq$ 10000 K	$T_{\rm eff}$(phot) $>$ 10000 K	All
n	19	9	28
$< \Delta\pi/\pi >$ (%)	8.9	13.2*	10.1*
$< \Delta \log T_{\rm eff} >$**	−0.005	−0.003	−0.004
rms: σ	0.013	0.065	0.037

* CW Cep not included
** $\Delta \log T_{\rm eff} = \log T_{\rm eff}({\rm Hip}) - \log T_{\rm eff}({\rm phot})$

triple system, but the poor quality of the photometry of the third component did not allow us to obtain additional information about its distance. The visual companion may have had a marked effect on the determination of the parallax and this may be an additional source of uncertainty not included in the formal error.

Table 1 summarizes the statistics of the differences between temperature determinations considering the stars hotter and cooler than 10000 K in separate subsamples. The mean difference is compatible with zero in both cases, suggesting that, as seen in the plots, no systematic effects are present either as a function of the temperature or as a function of the distance. Moreover, no difference in behaviour is found between those systems with effective temperatures obtained through Johnson calibrations and those systems with effective temperatures calculated through Strömgren photometry.

5. RS CVn-TYPE SYSTEMS

The photometric temperatures were computed through the individual $(B-V)_\circ$ indices extracted from the literature and by using Popper's (1980) calibration. The V magnitudes used to compute Hipparcos temperatures were corrected for the light loss associated with the spotted surfaces, which is especially large for the secondary stars. Additionally, the cooler stars in the sample ($T_{\rm eff}$ $\lesssim$4000 K) were not taken into account due to the limited range of validity of the BC calibration.

As shown in Figure 3, the difference between temperature determinations is contained within 1σ of the detached systems for most of the stars. For those stars which are not contained in the $1\sigma_{\rm detached}$ interval, the Hipparcos temperature tends to be systematically lower than the photometric value, suggesting that the correction due to the spotted surfaces may be underestimated.

Table 2 summarizes the statistics of the differences between temperature determinations. We can conclude that the photometric temperatures agree very well with those coming from Hipparcos parallax, and no clear systematic effects are seen although there are few stars in the sample. The agreement means that the adopted BC and the calibrations relating

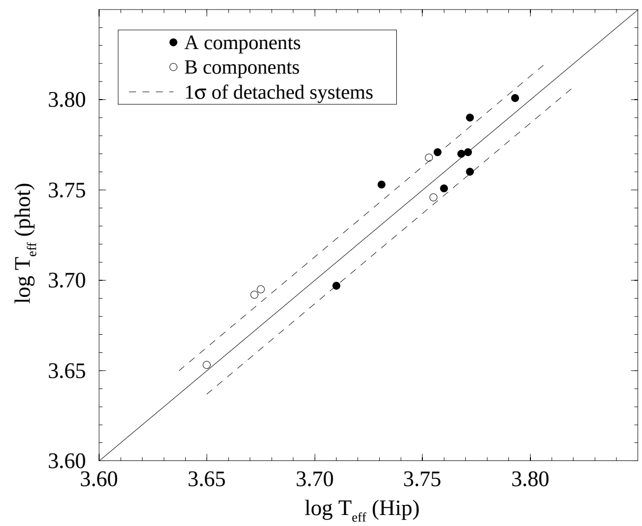

Figure 3. Hipparcos versus photometric determinations of effective temperature for the RS CVn-type binaries. The dashed line is 1σ interval corresponding to the detached systems in the same temperature range.

Table 2. Statistics of the difference between the Hipparcos parallax-based and the photometric determination of effective temperatures for the RS CVn-type systems. n is the number of stars in each subsample.

	A comp.	B comp.	All
n	9	5	14
$< \Delta\pi/\pi >$ (%)	10.3	9.0	9.8
$< \Delta \log T_{\rm eff} >$*	−0.003	−0.010	−0.005
rms: σ	0.014	0.016	0.014

* $\Delta \log T_{\rm eff} = \log T_{\rm eff}({\rm Hip}) - \log T_{\rm eff}({\rm phot})$

$T_{\rm eff}$ and $(B-V)_\circ$ are suitable. This is a remarkable result, since the temperatures involved are very low, between 6300 and 4500 K.

6. ALGOL-TYPE SYSTEMS

The unification of the photometric temperatures was not possible, since the $(B-V)_\circ$ index of the components is not available in the literature for all of the systems. For half of them, $(B-V)_\circ$, $(V-R)_\circ$ or $(b-y)_\circ$ was available and Popper's (1980) calibration was used. The temperatures of the remaining systems were adopted from the literature, mainly coming from spectral fittings or spectral type-temperature relations.

Due to the faintness of the secondary components, their colour indices are unreliable and the temperatures are usually derived from light curve analysis when the temperature of the primary component is fixed. So, the inaccuracies in the temperature of the bright component have a critical effect on that of the faint one.

Figure 4 shows the comparison between the Hipparcos and the photometric determinations of effective

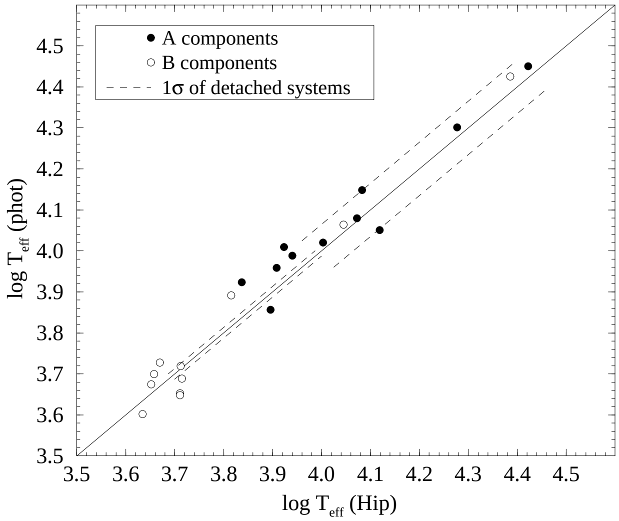

Figure 4. Hipparcos versus photometric determinations of effective temperature for the Algol-type binaries. The dashed lines are 1σ intervals corresponding to the detached systems in the same temperature ranges.

Table 3. Statistics of the difference between the Hipparcos parallax-based and the photometric determination of effective temperatures for the Algol-type systems. n is the number of stars in each subsample.

	$T_{\rm eff}$(phot) $\leq$ 10000 K	$T_{\rm eff}$(phot) $>$ 10000 K	All
n	9	13	22
$< \Delta\pi/\pi >$ (%)	11.1	13.2	12.0
$< \Delta \log T_{\rm eff} >^*$	−0.014	−0.024	−0.018
rms: σ	0.054	0.050	0.051

$^*\Delta \log T_{\rm eff} = \log T_{\rm eff}({\rm Hip}) - \log T_{\rm eff}({\rm phot})$

temperatures. Algol-type systems show a larger scatter than the detached and RS CVn-type systems, for temperatures below 10000 K. Nevertheless, no remarkable systematic behaviour is found (Table 3) since the mean temperature differences are compatible with zero.

It has been pointed out that the temperatures of the components of these systems are difficult to obtain photometrically. If we consider that the input parameters are not likely to be influenced by the peculiarities of the stars in Algol-type systems, it may be concluded that the temperatures from Hipparcos parallax are more realistic than the temperatures derived from photometric calibrations.

7. CONCLUSIONS

A comparison between the photometric effective temperature and a determination using the Hipparcos parallax was performed for a sample of detached eclipsing binaries. Since these determinations were completely independent, we conclude that the standard photometric calibrations are free of systematic errors to the level of accuracy provided by Hipparcos measurements.

The same test was extended to a sample of RS CVn-type eclipsing binaries, and the photometric temperatures were consistent with the Hipparcos-parallax based temperatures, even for stars with temperatures as low as 4500 K.

Finally, several Algol-type systems were also analyzed, and, although no systematic behaviour was found, the scatter was larger than that of the detached systems. However, the Hipparcos parallax-based temperatures appear to be more reliable than those computed using standard photometric calibrations.

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