TEMPLOGG – determination of stellar parameters

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ABSTRACT

We provide an overwiew on the TEMPLOGG tool for determination of fundamental stellar parameters from photometric observations. TEMPLOGG provides a very convenient access to a variety of calibrations for the Strömgren–β and the Geneva photometric systems by performing an automatic selection of the most suitable transformation between observed colours and stellar parameters while requiring only observed photometric indices as input data. The tool has already been used during preliminary studies in preparation for COROT to find out about its efficiency and reliability in comparison with spectroscopic methods discussed elsewhere in these proceedings.

1. Introduction

Stellar fundamental parameters may be determined either through direct observations in which case one considers, e.g. the derived effective temperature, as a truly fundamental quantity, or by indirect methods based on theoretical models or some experimental calibration. Direct methods are only applicable to a very small number of stars, and for some parameters such as metallicity fundamental methods simply do not exist. Thus, for applications such as the COROT mission preparation, only indirect methods are feasible. Among them, photometric calibrations provide the fastest and least resource demanding approach. There are two obvious questions related to any application of photometric calibrations: which of them to choose among the many existing ones and how to find out about their reliability.

The TEMPLOGG program helps to answer the first of these questions and partially also provides an answer to the second one for the case of the Strömgren–β and for the Geneva photometric system. We provide a description of the purpose of TEMPLOGG, its authors, and the structure of the program. We discuss its capabilities, in particular how different calibrations are automatically selected on just evaluating the observed photometric indices, and finish with examples for both photometric systems based on COROT target stars.

2. Purpose of TEMPLOGG

The main purpose of TEMPLOGG is the determination of $T_{\rm eff}$, $\log g$, and metallicity from observed colours. To obtain these quantities the program requires either complete data for Strömgren-β photometry ($b-y$, c_1, m_1, β, V), Geneva photometry ($U-B$, $B1-B$, $B2-B$, $V-B$, $V1-B$, $G-B$), or both.

The idea of the program is to select the most suitable among a number of calibrations known to the program using the observed colour indices as input and derive $E(b-y)$, $T_{\rm eff}$, $\log g$, metallicity, and $M_{\rm v}$. Some of these quantities cannot be derived for all regions of the HR diagram, either because the photometric systems are not sensitive to it, or because no suitable calibrations exist. For the Geneva system, the reddening can be determined if $E(b-y)$ is known, for example after application of TEMPLOGG to the Strömgren-β photometric data for the same star. Otherwise, $E(B2-V1)$ has to be supplied from other sources, because the system can be rather sensitive to reddening (cf. the example in Rogers 1995).

3. Authors and Structure of TEMPLOGG

The "templogg" program is a menu driven application written in the C-Shell script language by Rogers 1995. It provides a convenient access to the different Fortran codes which perform the inversions from observed colour indices to fundamental parameters and it also enables the user to process tables of photometric data for a list of stars in batch form.

The Fortran computer programs used for processing Strömgren-β photometric data have been developed by Fresno 1994. They are based mainly on the calibrations of Moon & Dworetsky 1985 and Napiwotzki et al. 1994, complemented by a number of other calibration work required to determine reddening, absolute magnitudes, and metallicity (for details see Rogers 1995).

For the case of Geneva photometry, both calibration and Fortran computer codes were first published by North et al. 1994 at the 22nd IAU General Assembly, which is the form of the Geneva calibration still used by TEMPLOGG.

4. Capabilities of the TEMPLOGG tool

For both Strömgren–β and Geneva photometry the TEMPLOGG program only requires the observed colour indices and the observed magnitude as input. For the Geneva system the reddening index $E(B2-V1)$ has to be known as well, and in some parameter ranges of the HR diagram, preliminary estimates for the metallicity are needed. Consequently, Geneva photometric data is best used as a creoss-check of the Strömgren–β results, which can be used to derive the extra information required for the Geneva system.

When processing Strömgren–β photometric data, an elaborated case consideration is processed using $b-y$, m_1, H_β, and $u-b$ (derived from c_1, m_1, and $b-y$). Incomplete Strömgren–β can thus not be used for parameter determination through TEMPLOGG. The selection procedure was originally developed for

A stars (Figueras et al. 1991) and later extended to cover the entire application range of this photometric system (Fresno 1994). A flow chart example can be found in Rogers 1995 (Fig. 1). After one of eight known calibration regions has been selected, the fundamental parameters are computed using the chosen calibration. The eight regions include the main sequence (B stars, early A stars, late A stars, F to solar type stars, and stars cooler than the sun) and supergiants (early, A to mid F type, and mid F to G type). For stars with chemical peculiarties, or, in general, above the main sequence, the calibrations may not always be applicable or at least ambiguous. In this case, warnings are issued by the program though it still attempts to select the most useful calibration according to the data. An example relevant for the COROT programme is given below. A more detailed description, including references to the proper calibrations, can be found in Rogers 1995.

An equivalent procedure is applied by TEMPLOGG to Geneva photometric data. In that case, three calibration regions are considered (for B stars, early A stars, and stars cooler than early A type). They correspond to the applicability range of the calibrations of the X–Y indices, the pT–pG indices, and the indices $B2-V1$, d, and m_2 that can be derived from the Geneva photometric colours. A flow chart of the calibration selection can be found in Rogers 1995.

The fundamental parameters derived by TEMPLOGG are best explained using an example to which we proceed below. Other capabilities of TEMPLOGG include file handling for output data to allow batch processing, a tutorial which makes the program self-explanatory, and the possibility to use both observed ($U-B$, etc.) and derived ($B2-V1$, d, $\ldots$) indices as input for the Geneva photometric calibration program. We note that in principle all the calibration programs used by TEMPLOGG could also be called directly. This could be of interest if a calibration different from the one proposed by TEMPLOGG should be used, for example, when warnings on the validity range have been issued for a particular star. However, whatever calibration may be used instead is most likely applied outside the range of its validity, which makes the direct usage of these programs not only less convenient, but also provides no practical advantage.

5. Examples and some results relevant for the COROT mission preparation

We begin with an example for HD 43318, a potential COROT target star, using the most recent Strömgren–β photometric data available from SIMBAD. Table 1 displays both the input required by the program, and output issued on file.

Currently, the projected rotational velocity is used only for information purposes, similar to the label "Ident.", while the observed V magnitude is required to compute the stellar distance in parsec. The four photometric indices are the only mandatory input. They are used to determine the calibration region (in this case region 4 for each of $E(b-y)$, M_v, and $[FE/H]$, which corresponds to F0 to G2 type main sequence stars) and the dereddened Strömgren indices $(b-y)_0$, m_0, and c_0. The calibration is then used to compute the results displayed in the bottom line of Table 1. Besides the reddening $E(b-y)$, they include luminosity and metallicity indicators δc_0 and δm_0, the absolute magnitude M_v, the distance in parsec (ro), the bolometric correction (dmb), and finally the most important quantities: $T_{\rm eff}$ in K, $\log g$ in CGS units, and metallicity

```
 Identification [Star]: HD43318
     V [6]: 5.65
 (b-y) []: 0.320
    m1 []: 0.154
    c1 []: 0.447
H Beta []: 2.646
v sini [0]:


 Ident.   (b-y)    V      m1    c1     Hb    vsini region  (b-y)0   m0     c0

HD43318   0.320  5.650  0.154  0.447  2.646   0.0 44 4 MS  0.310  0.157  0.445



E(b-y)  dc0    dm0     Mv     ro   dmb    TEFF  LG  [FE/H]

0.010  0.063  0.023    3.28   29   0.66   6421 4.21 -0.14
```

Table 1: Output in file mode of TEMPLOGG for Strömgren-β photometry applied to HD 43318.

[FE/H] relative to the solar value adopted by the individual calibrations. The metallicity can only be derived for three out of the eight possible calibration regions, i.e. for main sequence stars later than about A3. A dummy value of 9.99 is displayed otherwise. Occasionally, also δc_0 may not be computable, in which case the same value of 9.99 would be provided (cf. the example in Rogers 1995).

For the same star we also know Geneva photometric data which is displayed in Table 2. It is instructive to repeat the experiment for this star. The results are shown in Table 3, where we have also illustrated the effect of reddening on the fundamental data derived.

index	$U-B$	$V-B$	$B1-B$	$B2-B$	$V1-B$	$G-B$
GEN m	1.309	0.366	1.003	1.365	1.105	1.440

Table 2: Geneva colours for HD 43318.

The reddening $E(B2-V1)$ is approximately 0.011. From Table 3 we conclude that such amount of reddening introduces uncertainties of about 60 K in T_{eff}, 0.09 dex in $\log g$, and 0.03 dex in metallicity, if it were not known in advance. This ranges from about half to twice the size of the internal calibration error derived by the program. Thus, unless the reddening is small, a reasonable estimate of $E(B2-V1)$ can significantly improve the reliability of results from the Geneva photometric calibration for T_{eff} less than 11 000 K (calibrations 2 and 3, cf. Rogers 1995). Similar to Strömgren–β photometry, metallicity can also only be determined for stars of spectral type later than about A3 (calibration 3) and chemical peculiarities of a star may decrease the reliability of the results. Undetermined parameters and program fails are indicated by asterisks and warning messages, similar to the Strömgren–β case. We note that for some calibration regions the metallicity has to be guessed first (with values of -1, 0, and +1) and the program may have to be reinvoked twice for the same star, in case the metallicity is expected to be different from the solar one. If quantities other than $T_{\rm eff}$, $\log g$, or metallicity are of interest, the Strömgren–β calibration has to be used.

```
Star            Teff                Logg                 [M/H]        E(B2-V1)

HD43318     6193 +-    34(1)     3.63 +- 0.14(1)     -0.22 +- 0.08(1)     0.00
HD43318     6252 +-    36(1)     3.72 +- 0.13(1)     -0.19 +- 0.08(1)     0.01
HD43318     6313 +-    37(1)     3.81 +- 0.13(1)     -0.16 +- 0.07(1)     0.02
```

Table 3: Output in file mode of TEMPLOGG illustrating reddening dependence of fundamental parameters for HD 43318 based on Geneva photometric data. Error ranges refer to internal (calibration specific) error contributions. The empty “Remarks” column has been removed from this example.

The absolute error estimates for the calibrations in both photometric systems range from 150 K in $T_{\rm eff}$ for cool stars to 250 K for hot ones, while a range of 0.15 to 0.20 dex is estimated for $\log g$. However, these estimates may appear rather optimistic: the Geneva calibration is partially based on the original Kurucz ATLAS9 grids (Kurucz 1993), while the work of Napiwotzki et al. 1994 used the old Kurucz ATLAS6 grids (Kurucz 1979) which thus influences the accuracy of the Strömgren–β calibration. Application to numerous B to F type stars, including many chemically peculiar ones, and comparison with spectroscopic methods by the group of Werner Weiss at the Vienna Observatory has shown that these estimates are reliable at least in an internal sense. This means that abundance analyses based on Kurucz type model atmospheres usually yield values for $T_{\rm eff}$ within the quoted range. For $\log g$ the difference is occasionally larger. Of course, the results are getting worse for stars with strong chemical peculiarities. Nevertheless, we have found at least $T_{\rm eff}$ to agree almost always within a few hundred K.

To determine whether the accuracy achieved with TEMPLOGG is comparable with other methods intended for the fundamental parameter determination of COROT target stars, we used the program to determine $T_{\rm eff}$ and $\log g$ using Strömgren–β and, where available, Geneva photometry and compared it with results from spectroscopic analysis. As we can see from Table 4 the different methods provide results which essentially match within the expected error range. We note that Geneva data was used without dereddening. However, the reddening effects should be less than 100 K in these cases and their inclusion would essentially provide slightly higher temperatures (see Table 3).

6. Conclusion

TEMPLOGG provides an easy way of using Strömgren–β and Geneva stellar photometric calibrations. The derived stellar parameters compare well with much more expensive spectroscopic methods. TEMPLOGG is thus a valuable tool both for a first guess of stellar fundamental parameters in spectroscopic analyses and for computing these parameters for extensive catalogues of stars, as for example the list of

method	quantity	HD 43587	HD 43318	HD 45067	HD 49933	HD 49434
Templogg	$T_{\rm eff}$					
Geneva			6193		6789	
Strömgren–β [E(b-y) = 0]		6009	6420		6535	7321
Strömgren–β [E(b-y) $\neq$ 0]			6421		6535	7321
Spectroscopic	$T_{\rm eff}$	6000	6250	6000	6500	7250
Templogg (Strömgren–β)	$\log g$	4.32	4.20		4.25	4.16

Table 4: Fundamental stellar parameters of some potential COROT targets.

potential COROT target stars. An immediate improvement which could be useful for the application of TEMPLOGG to COROT targets is the inclusion of an "additional loop" within TEMPLOGG to account for estimates in the photometric input data themselves by repeated application of the program to the different parameter combinations. This would permit to account for both internal and external errors.

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