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# Physical parameters for TGAS stars

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## Abstract

The Tycho-Gaia Astrometric Solution (TGAS) catalogue contains positions, parallaxes, proper motions and $G$ magnitudes for more than 2 million stars. It was released in September 2016 as part of the Gaia Data Release 1 (DR1). In this work we investigated some methods to get additional information, in particular the effective temperature, the surface gravity and metallicity, but also reddening, absolute magnitudes or bolometric corrections, for TGAS stars. We have also searched for radial velocities in the Gaia-ESO Survey (GES).

## 1 Introduction

In September 2016 the Gaia astrometric mission released the first set of data (DR1) [4], based on the first fourteen months of scientific observations. One of the products included in DR1 is the Tycho-Gaia Astrometric Solution (TGAS) catalogue [11], with position, parallax, proper motions and $G$ magnitude for 2,057,050 stars. TGAS takes advantage of the previous knowledge of the positions of the stars in the Tycho-2 catalogue [9], measured more than twenty years before, to compute parallax and proper motions. The median uncertainty of TGAS is better than 0.32 mas in position, 0.32 mas in parallax and 1.32 mas$^{-1}$ in proper motion.

In order to complement TGAS with astrophysical information, we investigate some methods to compute additional parameters like the effective temperature $T_{\rm eff}$, the surface gravity and metallicity. This astrophysical information combined with the Gaia parallaxes allows to determine fundamental parameters of the stars, as radius, luminosity and mass.

Firstly, we describe (Sect. 2) the use of the Strömgren-Crawford indexes to compute physical parameters; in Sect. 3 we use the Infrared Flux Method (IRFM) for the same purpose, in this case we get also the angular semi-diameter and the bolometric correction. Finally, in

Sect. 4 we explain the use of Virtual Observatory Sed Analyzer (VOSA). The discussion of the results is presented in Sect. 5.

## 2 Physical parameters from Strömgren photometry

The Strömgren-Crawford (or $uvby - H_\beta$) photometric system [15] has been widely used to compute reddening, absolute magnitudes, metallicities, effective temperature and surface gravity (see for instance [5], [6] or [13] ). These parameters are computed via empirical calibrations, using the photometric colours $(b-y)$, $m_1$, $c_1$ and $H_\beta$ (together with the indexes $\delta m_1$ and $\delta c_1$) as independent variables. As the role of the photometric indices could change with the temperature (for instance $c_1$ is a temperature indicator for B and A type stars, but a luminosity indicator for F, G and K type stars), we need to preclassify the stars according to their spectral type (and also luminosity class), using the photometric colours. More details on the calibrations and classification algorithm can be found in [10]. The expected errors are 150K for $T_{\rm eff}$, 0.18 dex for $\log g$ and 0.10 dex for $[m/H]$.

Paunzen [14] has compiled the available $uvby - H_\beta$ for the Tycho-2 stars. We have used this new catalogue to compute the physical parameters for the 27,413 TGAS stars included in Paunzen´s catalogue with complete photometry and with their photometric indices inside the range of validity of the calibrations. The results are compared with the determinations from other methods in Section 5.

## 3 The Infrared Flux Method

The use of IR photometry to determine effective temperatures was initially proposed by Blackwell & Shallis in 1977 [3]. Their so-called Infrared Flux Method (IRFM) uses the ratio between the bolometric flux of the star and the monochromatic flux at a given infrared wavelength, both measured at Earth, as the observable quantity. This ratio is then compared with a theoretical estimate derived from stellar atmosphere models to carry out the determination of the effective temperature. The IRFM has been widely used by several authors, being most noteworthy the work by [1].

The method that we propose is slightly different from the Blackwell & Shallis method. It is based on the Spectral Energy Distribution Fit (SEDF) from the optical ($V$) to the IR ($JHK$) using synthetic photometry computed from stellar atmosphere models (see [12]). The fitting algorithm minimizes the difference between observed and synthetic photometry by tuning the values of the effective temperature and the angular semi-diameter, through the minimization of the $\chi^2$ function defined from the differences between observed (corrected of interstellar extinction) and synthetic $VJHK$ magnitudes, weighted with the corresponding error:

$$\begin{aligned}\chi^2 &= \left(\frac{V - A_V - V_{\rm syn}}{\sigma_V}\right)^2 + \left(\frac{J - A_J - J_{\rm syn}}{\sigma_J}\right)^2 + \\ &+ \left(\frac{H - A_H - H_{\rm syn}}{\sigma_H}\right)^2 + \left(\frac{K - A_K - K_{\rm syn}}{\sigma_K}\right)^2 \end{aligned} \quad (1)$$

This function depends (via the synthetic photometry) on $T_{\text{eff}}$, $\log g$, $[m/H]$ and a magnitude difference $\mathcal{A}$, which is the ratio between the synthetic (star's surface) and the observed flux (Earth's surface). $\mathcal{A}$ is directly related to the angular semi-diameter by the following expression:

$$\theta = 10^{-0.2\mathcal{A}} \tag{2}$$

Since the SEDF method provides both effective temperature and angular semi-diameter, it also naturally allows for the determination of the bolometric correction in a specific band (see [12] for a detailed discussion).

As virtually all the TGAS stars have $JHK$ photometry obtained from the $2MASS$ catalogue [7], we could apply this method to the whole TGAS catalogue. However, in the current implementation, the method is restricted to main sequence stars with effective temperature between 5000K and 8500K, although some authors have extended it to other regions of the HR diagram [2].

The IRFM needs of the knowledge of $\log g$ and $[m/H]$. However, the value of the effective temperature computed with the IRFM shows only a small dependence with them, in such a way that, if they are not available, we could assume a value (for instance the solar one) with little impact in the final result. For instance, assuming and error in $\log g$ equal to 0.18 dex and in $[m/H]$ equal to 0.10 dex, we expect an error of 1.5% in effective temperature and 2.0% in the angular semi-diameter. Despite this, we have preferred to apply the IRFM only to stars with good determinations of $\log g$ and $[m/H]$, i.e. those stars with spectroscopic values or with values determined from $uvby-H_\beta$ photometry as explained above. This allows a better comparison with other methods. In total we have applied the IRFM to 25,652 TGAS stars.

## 4 VOSA

VOSA (VO Sed Analyzer) is a tool developed by the Spanish Virtual Observatory. After reading user photometry-tables or query several photometric catalogs accessible through VO services (increasing the wavelength coverage of the data to be analyzed), VOSA performs an statistical test to determine which atmosphere model reproduces best the observed data. In this way it provides a set of physical parameters, including effective temperature, surface gravity, metallicity and bolometric correction. VOSA also provides an estimation of the mass and age of each source. The extinction can be set by the user or fitted at the same time of the other parameters. VOSA runs via web at http://svo2.cab.inta-csic.es/theory/vosa/index.php.

## 5 Comparisons

As an example, Fig. 1 and 2 show the comparison between the effective temperatures computed from Strömgren-Crawford photometry, IRFM and VOSA. The first comparison (Strömgren-Crawford photometry vs. IRFM) shows a difference of 74K, being highest the IRFM temperature, with $\sigma = 360$K. In addition, there is a slight trend of the difference with the

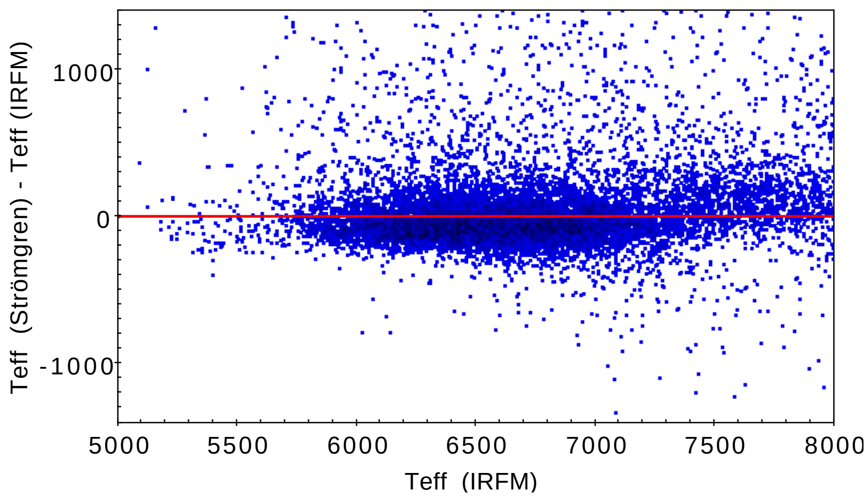


Figure 1: Comparison of the effective temperatures computed from Strömgren-Crawford photometry and from IRFM for 11269 TGAS stars..

temperature.

The comparison between VOSA and Strömgren-Crawford photometry for a group of 463 stars is shown in Fig. 2. The difference $|T_{\rm eff}$ Strongrem $- T_{\rm eff}$ VOSA$|$ is less than 250K for 80% of the stars, and slightly better if we consider only the interval 5000 K -9000 K.

## 6 Conclusions

In this preliminary work we have explored the possibility to add additional astrophysical information to the TGAS catalogue using different methods. We have analyzed the use of the Strömgren-Crawford photometry, the Infrared Flux Method and VOSA to compute parameters as effective temperature, surface gravity, metallicity, reddening or bolometric corrections. The methods have been applied to a small subset of the TGAS stars, restricted by the relatively small number of stars with complete $uvby - H_\beta$ photometry and for to the need to a prior knowledge of $[m/H]$ and $\log g$ to increase the accuracy of the IRFM. In the case of effective temperature the methods shows a good agreement, but with some dependences of the differences with the temperature. Other parameters, like metallicity or surface gravity, have not yet been analyzed.

We have also looked for additional parameters, as radial velocities, in surveys like the on-going Gaia-ESO Survey (GES) [8]. Unfortunately, only a few hundred of TGAS stars have been observed by GES.

According to the data release scenario of the Gaia mission the spectrophotometric data of the mission should be released as part of the data release 3 (DR3) in 2018. When available, we will have a complete and homogeneous determination of the physical parameters for more than one billion stars. In the meanwhile, we have to use the current available methods,

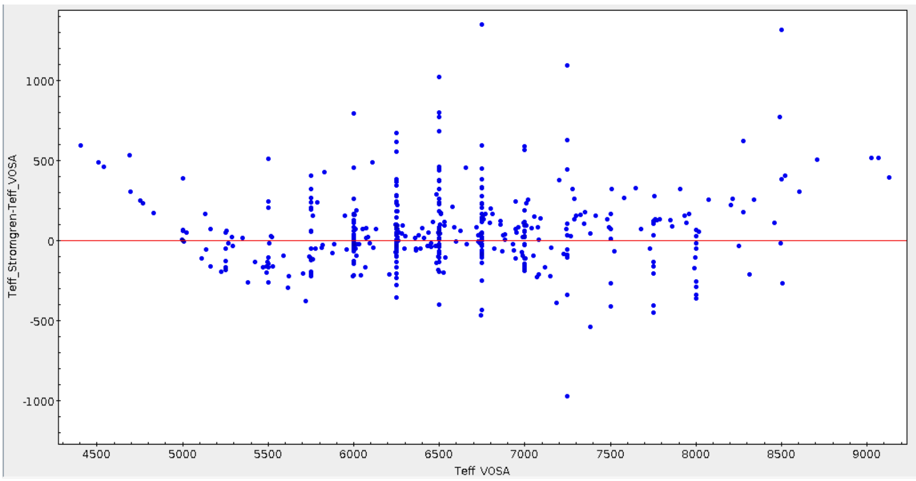


Figure 2: Comparison of the effective temperatures computed from Strömgren-Crawford photometry and from VOSA for 463 stars.

like the ones described here, to complement the astrometric information of Gaia with the astrophysical parameters.

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