Comparison between MAFAGS-OS spectra and Kurucz-ODF spectra

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Abstract. Grids of theoretical stellar spectra are fundamental for estimating basic stellar parameters from photometric and spectroscopic data observed in large sky surveys such as SDSS, LAMOST, Gaia, etc. Do the different atmosphere models influence the parameters estimation? We compute the Lick indices and uvby color indices using the MAFAGS-OS grid of model atmospheres and fluxes provided by F. Grupp (personal comm.) and the Kurucz grids [1]. A spectrum comparison reveals the behavior of spectra from the MAFAGS and Kurucz grids.

We find that using the (b-y) index, consistent effective temperatures can be determined from both the Kurucz and MAFAGS grids of theoretical spectra. The m1 index, together with color index, can be used to determine the metallicity of F- and G-type stars, but the measurements of the Kurucz and MAFAGS grids show systematic discrepancies for cool stars. The c1 indices computed with both grids show small discrepancies for \( T_{\text{eff}} < 6000 \) K, while for \( T_{\text{eff}} > 6000 \) K, the c1 indices agree well.

The Lick indices of the Kurucz grid and the MAFAGS grid tend to be in agreement for warm stars with temperatures above 5000 K, while for cool stars with temperatures ranging from 4000 K to 5000 K, the difference of Lick indices for both models is apparently large.

We also compare the MAFAGS spectrum and Kurucz spectrum of the same temperature, surface gravity, and metallicity using a correlation coefficient for the complete spectrum. For warm stars, the MAFAGS and Kurucz spectra are almost the same, while for cool stars below 5000 K, there are some discrepancies between the MAFAGS and Kurucz spectra that induce internal discrepancies in the parameters determination.

1. Introduction
Many large sky surveys focus on unraveling the structure, formation history, kinematics, and evolution of the Milky Way. For sky surveys such as SDSS, Gaia, LAMOST, etc., accurate and reliable stellar parameters automatically derived from a huge amount of low-resolution spectra are important for accomplishing the science goals. Many methods have been developed to solve this problem. The methods based on spectroscopy usually require a set of spectra for which the parameters have been accurately calibrated by constructing a grid of template spectra or training sets. There are two ways to construct a grid of template spectra. One is based on libraries of empirically observed spectra from ELODIE, MILES, etc. The other uses theoretical stellar spectra computed from stellar atmosphere models, such as the Kurucz models [2,3], the MARCS models [4], and the PHOENIX models [5], etc. Compared to observed spectral grids, theoretical stellar grids are more complete and uniform, having a large density of parameters coverage. While theoretical spectral grids have their shortcomings (although various
stellar atmosphere models are widely used in stellar evolution and flux analyses, etc.) their
development is still in progress. Atmosphere models that are based on a series of simplified
assumptions yield theoretical spectra different from observed spectra. Furthermore, different
treatments of the basic assumptions for the calculation of the models make them different from
each other. Does the difference between stellar atmosphere models influence the measurement
of stellar parameters using low-resolution theoretical spectra as templates? In case theoretical
spectral grids are employed for parameter estimations with low-resolution spectra, the systematic
errors that result from differences in the theoretical spectral grids should be studied.

In this paper we select the MAFAGS and Kurucz grids of theoretical spectra to investigate if
there are differences in the measurement of parameters from low-resolution spectra. The method
compares photometric color indices, absorption line indices, and a complete spectrum matching
is performed to determine the temperature, surface gravity, and metallicity from both grids. In
this paper we do not consider different $\alpha$-enhancements in the models.

2. MAFAGS-OS and ATLAS9-newODF atmosphere models

We use the MAFAGS-OS atmosphere models of the spectral grid provided by Grupp
[6,7,8], and the ATLAS9-newODF atmosphere models of [1] (online available from
http://wwwuser.oat.ts.astro.it/castelli) and SPECTRUM [10] to construct the grid of
theoretical spectra. As was shown by [6,7] and [11], the MAFAGS models are almost identical
to the commonly used Kurucz models. Both model grids are valid for A-, F- and G-type
stars. They produce almost identical spectra for the same stellar parameters. Besides a number
of special treatments for the calculation of convection and the wavelength grid sampling, the
main difference between both models is the opacity calculation. MAFAGS-OS is an opacity
sampling (OS) code, while ATLAS9-newODF is based on opacity distribution functions (ODF).
[6] summarized the difference between OS and ODF models and illustrated the theoretical 
flux distribution in OS and ODF models. Convection in the MAFAGS models is treated following
[12], using a convective efficiency parameter of $\alpha_{cm} = 0.82$, whereas Kurucz (ATLAS9-newODF)
models use the mixing-length approach (ML) with a mixing-length to the pressure scale height
ratio of $l/H_p = 1.25$ [13]. Both theoretical spectral grids provide models with the same wavelength
coverage of SDSS and LAMOST. They range from 300 nm to 1000 nm, and are decreased from
high-resolution spectra to a resolution of $R=2000$ with a 0.1 nm wavelength sampling step.
$\alpha$-enhancement is not considered for both model grids because the effects are small for low-
resolution spectra of $R=2000$. The microturbulence velocity is held constant at 2.0 km s$^{-1}$ in
both grids. The MAFAGS-OS grid comprises of 9841 spectra with $T_{\text{eff}}$ ranging from 4600 K
to 15000 K in steps of 200 K for cool stars, while 500 K for warm stars. The log $g$ parameter
ranges from 0.0 dex to 5.0 dex in steps of 0.2 dex, and the metallicity [Fe/H] ranges from 0.0 dex
to $-4.8$ dex in steps of 0.3 dex. The Kurucz grid comprises of 3929 spectra with $T_{\text{eff}}$, ranging
from 3500 K to 50000 K in steps of 250 K for cool stars, and 1000 K for warm stars. The log $g$
parameter ranges from 0.0 dex to 5.0 dex in steps of 0.5 dex, and the metallicity [Fe/H] ranges
from 0.5 dex to $-4.0$ dex in steps of 0.5 dex.

3. Comparison method

With multi-fibre sky surveys employed in succession, various methods have been developed to
automatically determine parameters from low-resolution spectra. The most popular methods
generally consist of three types; parameter calibrations based on absorption line indices,
photometric color indices, and template matching or statistical learning methods that use
spectroscopy. To check if different theoretical spectral grids induce systematic discrepancies
in the parameter measurements we compare low-resolution grids of MAFAGS and Kurucz from
three points of view; theoretical colors, theoretical line indices, and a full spectrum comparison.
3.1. Comparison with uvby color indices

The uvby color indices $c_1 = (v - b) - (b - y)$ and $m_1 = (u - v) - (v - b)$ are verified by many researchers for being sensitive to temperature, surface gravity, and metallicity. Several empirical calibration formulae are offered in [14,15], [16], [17], and others, for converting $(b - y)$ to $T_{\text{eff}}$. [18] and [19] calibrated $[\text{Fe/H}]$ with the $m_1$-index for dwarf stars, while [20, 21] determined $[\text{Fe/H}]$ with the $m_1$-index for giant stars. The $c_1$-index can be used to determine the surface gravity of A- and F-type stars [22].

We synthesize the uvby photometric indices of both theoretical spectral grids using the theoretical spectrum of Vega as zero-point. Figure 1 shows the $(b - y)$ of both spectral grids in a $(b - y)$-metallicity diagram for $T_{\text{eff}}=5000$ K, 7000 K, 9000 K, and 12000 K. In each plot of constant $T_{\text{eff}}$ blue symbols mark the Kurucz grid, while red symbols mark the MAFAGS grid. Different symbols show different surface gravity values.

![Figure 1](image.png)

Figure 1. Comparison of the $(b - y)$-index for the Kurucz and MAFAGS grids. Each plot shows $(b - y)$ of both spectral grids in a $(b - y)$-metallicity diagram for $T_{\text{eff}}=5000$ K, 7000 K, 9000 K, and 12000 K. In each plot of constant $T_{\text{eff}}$ blue symbols mark the Kurucz grid, while red symbols mark the MAFAGS grid. Different symbols show different surface gravity values.
Figure 2. Comparison of the m1-index between the Kurucz and MAFAGS grids. In each plot of constant $T_{\text{eff}}$ red symbols mark the MAFAGS grid, while blue symbols mark the Kurucz grid. Others symbols as in Fig. 1.

agreement. Considering the accuracy of the observed photometric data, which shifts ($b-y$) by $\sim1-5\%$, e.g., most of the galactic reddening value in the map of [23] is small ($E(b-y)_{\text{urb}} < 0.04$), and its influence is smaller than the influence of the surface gravity parameter. Both the Kurucz and MAFAGS grids of low-resolution spectra can therefore utilize the ($b-y$) index for consistently determining $T_{\text{eff}}$.

Figure 2 shows the m1-index of both spectral grids in a m1 - metallicity diagram with $T_{\text{eff}}=5000$ K, 6000 K, 8000 K, and 10 000 K. In the plots for $T_{\text{eff}}>6000$ K, the m1-index of the Kurucz grid agrees well with the MAFAGS grid in the 3-D parameter space of $T_{\text{eff}}$, surface gravity, and metallicity. In the plot with $T_{\text{eff}}=5000$ K, the m1-index for the Kurucz grid and MAFAGS grids are discrepant for metallicity values exceeding $3.0$ dex. The m1-index is sensitive to the metallicity. The sensitivity is stronger for smaller $T_{\text{eff}}$. The m1-index combined with the ($b-y$) color index can be used to determine the metallicity of F- and G-type stars. However, there are systematic discrepancies between the Kurucz and MAFAGS grids for cool stars of $T_{\text{eff}}<6000$ K. If $T_{\text{eff}}$ is exactly 5000 K, for a m1-index between 0.05 and 0.2, the difference in metallicity determined from the MAFAGS grid and the Kurucz grid is as large as 2.0 dex. Therefore, considering the error in the $T_{\text{eff}}$ determination, the different m1-indices for stars with $T_{\text{eff}}<6000$ K obtained from the MAFAGS and Kurucz grids yield large differences in the metallicity that are clearly discrepant.

The c1-index is a good indicator of the surface gravity in A- and F-type stars. Figure 3 compares c1 to metallicity for the Kurucz and MAFAGS grids with $T_{\text{eff}}=5000$ K, 6000 K, 8000 K, and 10 000 K. The plots for $T_{\text{eff}}>6000$ K illustrate that the c1 indices for both theoretical
Figure 3. Comparison of the c1-index between the Kurucz and MAFAGS grids. In each plot of constant $T_{\text{eff}}$ red symbols mark the MAFAGS grid, while blue symbols mark the Kurucz grid. Others symbols as in Fig. 1.

Spectral grids are in agreement and are sensitive to the surface gravity. However, for stars of $T_{\text{eff}}\gtrsim10000$ K the sensitivity to the gravity parameter decreases with decreasing $T_{\text{eff}}$. In the second plot with $T_{\text{eff}}=6000$ K, the c1 indices of both grids agree for metal-poor stars. In case the metallicity exceeds $+1.0$ dex, the c1-index of the MAFAGS grid increases with increasing metallicity, whereas the c1-index of the Kurucz grid decreases with increasing metallicity. The differences in the c1-index for the MAFAGS and Kurucz models are maximum for the maximum metallicity value of $+0.5$ dex. These differences yield a maximum difference of $\sim1.1$ dex for the gravity parameter determined from both model grids.

3.2. Comparison with Lick line indices

The Lick line indices [24,25] are widely used for temperature, surface gravity, and metallicity measurements. They are well-suited for automatic determinations of basic stellar parameters with low-resolution spectra in a large sample of data. We calculate 25 Lick line indices following the standard Lick definition, and compare differences in Lick indices between both grids. In this paper we select three indices to investigate the differences. The indices are Fe4668, H$_\beta$, and Mg b. The nine contour plots in Fig. 4 illustrate the three Lick indices for Kurucz, MAFAGS, and the differences between them. The contour colors code the strength of the Lick indices of the lines, and the amount of difference between each pair of lines.

In Fig. 4 we show the difference of the line indices between both grids. There are many possible causes for these differences. They may for example result from the model grids, from the spectrum calculations, or from the computation of the indices. For practical applications,
Figure 4. The nine contour plots show three Lick indices of the Kurucz and MAFAGS models, Fe4668, H\_beta, and Mg\_b in the $T_{\text{eff}} - \log g$ diagram. The differences between the lines are also shown. From top to the bottom: Fe4668, H\_beta, and Mg\_b. From left to right: Lick indices of Kurucz, MAFAGS, and the difference between the lines of both models.

The line index calculations with real spectra can yield large errors because of noise in the local continuum flux. The errors in the Lick indices are however sufficiently small for low-resolution spectra and are useful for successfully determining stellar parameters in large surveys such as SDSS. For SDSS/SEGUE, the accuracy of $T_{\text{eff}}$ is $\sim 200$ K. The accuracy of the gravity is 0.2 dex, and also 0.2 dex for the metallicity. We find that in most contour regions the differences between two line indices stay rather small. A more precise accuracy criterion should be determined for various spectral resolutions. For the current experiment we roughly determine a criterion at $T_{\text{eff}}=5000$ K.

3.3. Comparison of the complete spectrum

The complete spectrum or a selected wavelength region can be utilized to obtain the stellar parameters with low-resolution spectra using statistical methods. This type of approach includes template matching, ANN (Artificial Neural Network), and regression methods. We currently employ a template matching method based on a correlation coefficient for comparing the complete spectra of both theoretical model grids. We select 46 pairs of spectra from both grids.
Correlation coefficients computed for 46 pairs of MAFAGS and Kurucz spectra. Upper panel: correlation coefficient with $T_{\text{eff}}$ for spectra of $[\text{Fe/H}]=-1.5$ dex. Lower panel: correlation coefficient with $T_{\text{eff}}$ for spectra of $[\text{Fe/H}]=0.0$ dex.

- ○ log $g=2.0$ dex; * log $g=3.0$ dex;
- × log $g=4.0$ dex; □ log $g=5.0$ dex.

with the same $T_{\text{eff}}$, surface gravity, and $[\text{Fe/H}]$. The 46 pairs of spectra range from low to high metallicity, from small to large $T_{\text{eff}}$, for surface gravities of dwarfs to giants. The comparison of MAFAGS and Kurucz spectra with the same parameters is performed by template matching based on a correlation coefficient.

Figure 5 shows the correlation coefficients of the 46 pairs of spectra from MAFAGS and Kurucz. The upper panel shows the correlation coefficient with $T_{\text{eff}}$ for spectra of $[\text{Fe/H}]=-1.5$ dex, while the lower panel shows spectra of $[\text{Fe/H}]=0.0$ dex. The different symbols mark the surface gravity. For spectra above 8000 K, the correlation coefficients of the MAFAGS and Kurucz spectra are above 0.99, while for spectra with $T_{\text{eff}}$ between 6000 K and 8000 K, the correlation coefficients are in the range of 0.98–0.99. For the spectra with $T_{\text{eff}}=5000$ K, the correlation coefficients are in the range of 0.90–0.97. Hence, for warm stars, the MAFAGS and Kurucz spectra are almost identical, while for cool stars below 5000 K, there are some differences.

4. Summary and conclusions
We compare the low-resolution spectral grids of MAFAGS and Kurucz to test if differences between these theoretical model grids influence our measurements of stellar parameters. We employ photometric color indices, absorption line indices, and the complete spectrum with a statistical learning method, for selecting uvby color indices, Lick indices, and template matching of the complete spectrum to investigate the differences between both model grids. We summarize the results as follows:

- both low-resolution Kurucz and MAFAGS grids can employ the $(b-y)$-index for determining $T_{\text{eff}}$.
- the m1-index can be used together with a color index to determine $[\text{Fe/H}]$ in F- and G-type stars, although our measurements with both grids reveal systematic discrepancies for cool stars.
- the c1 indices for both grids yield small discrepancies for $T_{\text{eff}}<6000$ K. For $T_{\text{eff}}>6000$ K the c1 indices of both grids agree well.
- the Lick indices of the Kurucz and MAFAGS grids tend to be in agreement for warm stars of $T_{\text{eff}}>5000$ K, while for cooler stars of $T_{\text{eff}}<5000$ K the differences in Lick indices for both models are apparently large.
- for warm stars of $T_{\text{eff}} > 5000$ K the MAFAGS and Kurucz spectra are almost the same, while for cooler stars below 5000 K, the MAFAGS and Kurucz spectra are clearly discrepant.
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