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New high resolution synthetic stellar libraries for the Gaia mission

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Abstract. High resolution synthetic stellar libraries are of fundamental importance for the preparation of the Gaia Mission. We present new sets of spectral stellar libraries covering two spectral ranges: 300÷1100 nm at 0.1 nm resolution, and 840÷890 nm at 0.001 nm resolution. These libraries span a wide atmospheric parameters range, from super-metal-rich to very metal-poor (-5.0 <[Fe/H]<+1.0), from cool to hot ($T_{\rm eff}$=3000–50000 K) stars, including peculiar abundance variations. Thanks to their spectral resolution, spectral type coverage and number of models, they represent a substantial improvement over previous libraries used in population synthesis models and in atmospheric analysis.

Key words. Stars: synthetic spectra – Stars: atmospheres

1. Introduction

ESA's Gaia mission, to be launched in 2011, is meant to obtain accurate position, parallax and proper motion for 10^9 objects all over the sky, up to magnitude G=20 ($V = 20 \div 22$) with an astrometric accuracy at the μ arcsec level, providing low-dispersion spectroscopy for each object and radial velocity measures up to G=16

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Table 1. Synthetic stellar libraries for Gaia. References: [1]Bouret et al. (2008),[2]Hindson et al. (2008), [3]Kochukhov et al. (2005), [4]Gustafsson et al. (2008), [5]Alvarez & Plez (1998), [6]Brott & Hauschildt (2005), [7]Castanheira et al. (2006)

Name	T_{eff} (K)	$\log g$	[Fe/H]	Notes
O,B,A stars [1]	8000 – 50000	1.0 – 5.0	-5.0 – +1.0	TLUSTY code, NLTE, wind, mass loss
sdO [2]	26000 – 100000	4.8-6.4	+0.0 0	TMAP, NLTE, $\Delta T_{\rm eff}$= 500 K, $\Delta \log g$= 0.2
A stars [3]	6000 – 16000	1.0 – 5.0	+0.0	Magnetic field
MARCS [4]	4000 – 8000	-0.5 – 5.0	-5.0 – +1.0	Variations in individual α-elements abundances
C stars [4,5]	4000 – 8000	0.0 – 5.0	-5.0 – +0.0	$\Delta T_{\rm eff}$= 500 K; [C/Fe]=0,1,2,3; [α/Fe]=+0.0, +0.4
PHOENIX [6]	3000 – 10000	-0.5 – 5.5	-3.5 – +0.5	$\Delta T_{\rm eff}$= 100 K; [α/Fe]=-0.2–+0.8, Δ[α/Fe]=0.2
Emission lines	≥ 15000	2.8 – 4.0	+0.0	Be, WR models
WD[7]	6000 – 90000	7.0–9.0		WDA & WDB, LTE

(for more details see Cacciari 2008, this meeting). The final catalogue is expected to provide the discrete classification of sources (single stars, galaxies, QSOs, asteroids), the astrophysical parameters (APs) for single stars (i.e. $T_{\rm eff}$, $\log g$,...) and possibly the parametrization of special sources (galaxies). Gaia will produce an unprecedented amount of data ($40 \div 50\ GB/day$) leading to 100 TB of compressed data in 5 years. This huge number of observed objects must be classified in an automated way. In the Gaia project, all the classification algorithms but one are based on supervised methods (see for example Bailer-Jones 2007), classifying a source or estimating its APs by comparison with a set of templates. In order to do this, simulations of Gaia observations covering the whole AP space are required: high resolution and high quality synthetic libraries are of fundamental importance. Here we focus on new stellar libraries, while galaxies, QSOs, asteroids are discussed elsewere (Tsalmantza et al. 2007; Claeskens et al. 2006; Warell & Lagerkvist 2007).

2. New stellar libraries

A large community of scientists has agreed to produce "state-of-the-art" libraries of synthetic spectra, with an homogeneous and complete coverage of the AP space at the two fixed resolutions required to produce Gaia simulations: 0.1 nm for the low-dispersion ($300 \div 1100$ nm) and 0.001 nm for the high resolution mode ($840 \div 890$ nm). The capability of reproducing real spectra is improving, and each code producing synthetic spectra is tuned for a given type of stars. These new libraries, summarized in Table. 1, span a large range in atmospheric parameters, from super-metal-rich to very metal-poor stars, from cool stars to hot, from dwarfs to giant stars, with small steps in all parameters, typically $\Delta T_{\rm eff}$=250 K (for cool stars), $\Delta \log g$=0.5 dex, Δ[Fe/H]=0.5 dex. Depending on $T_{\rm eff}$, these libraries rely on MARCS (F,G,K stars), PHOENIX (cool and C stars), KURUCZ, TLUSTY (A,B,O stars) models. These models are based on different assumptions: KURUCZ are LTE, plane-parallel, MARCS implements also spherical symmetry while PHOENIX and TLUSTY (hot stars) can calculate NLTE models both in plane-parallel and spherical symmetry mode (for a more detailed discussion see Gustafsson et al. 2008). MARCS spectra are also calculated including a global α enhancement (from -0.2 to 0.4 with a step of 0.2 dex). Moreover, enhancements of individual α elements (O, Mg, Si, Ca) are considered. Hot star spectra take into account the effect of magnetic field, peculiar abundances, mass loss, and circumstellar envelope (Be). In the next future, the calculation of stellar libraries in the very low temperature regime is foreseen.

The large overlap in the AP space among different libraries will allow their comparison. A large effort is ongoing in literature to compare spectra of different stellar libraries (see Gustafsson et al. 2008; Martins & Coelho 2007).

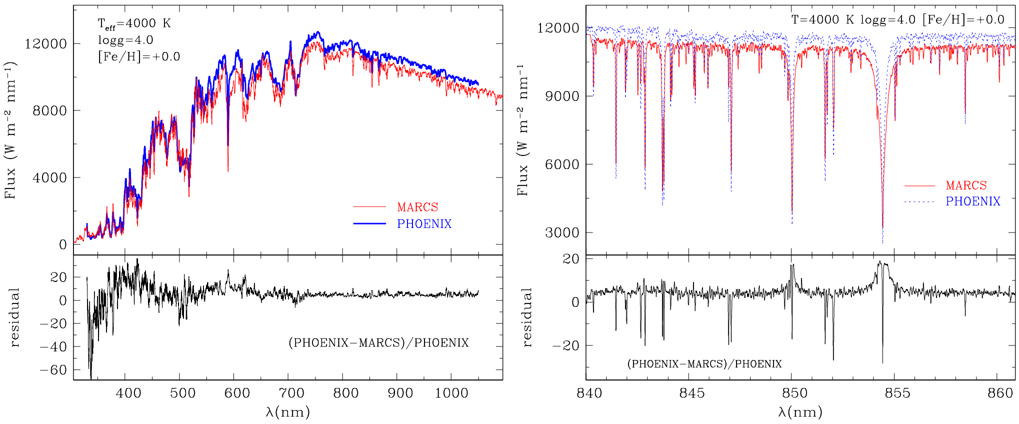

Fig. 1. Comparison between two different libraries (MARCS, PHOENIX) for a star having $T_{\rm eff}$=4000 K, log g=4.0, [Fe/H]=+0.0, in the BP/RP range (left) and in a selected region of the RVS range (right). Residuals (PHOENIX - MARCS)/PHOENIX are also shown in lower panels.

The impact of underlying assumptions, of different input physics (i.e. atomic and molecular line lists, convection treatment) or of the inclusion of NLTE effects, is shown in Fig. 1, where MARCS and PHOENIX are compared in the case of $T_{\rm eff}$=4000 K, log g=4.5, solar metallicity. In general, differences between the two libraries are of the order of 10%÷20% in the blue part of the spectrum, being worse for low temperature stars, as expected. Hot stars (O, B, A) are in agreement at the 1-2% level. Broad band colors (B-V, V-R, V-I) are good tracers of the flux distribution given by different libraries. Fig. 2 shows the comparison of some libraries at solar metallicity, for dwarfs and giant stars with the empirical calibration by Worthey & Lee (2006).

In Fig. 2 (upper panels) two sets of spectra of A stars are compared: A (Bouret), A (Kochukhov). They show a similar behavior and are a good reproduction of the empirical relations, in the diagram (V-R)-(V-I), where the residuals are < 0.05 mag. The agreement is worse in the (B-V)-(V-I) diagram.

In Fig. 2 (lower panels) two sets of spectra of F-G-K stars are compared: MARCS and BASEL (Lejeune et al. 1997). These libraries show a comparable agreement with the data. In the diagram (V-R)-(V-I), the residuals are < 0.07 mag, while in the (B-V)-(V-I) the residuals are of the order of ±0.1.

3. Conclusions

In this paper we summarize the work recently done by a large scientific community, resulting in the calculation of a large database of “state-of-the-art” synthetic stellar spectra, to be used in preparation of the ESA’s Gaia mission. They cover the whole optical range with 0.1 resolution and the Ca II triplet region at 0.001 nm resolution, for a large set of astrophysical parameters. Generally, these libraries are of great interest in stellar population synthesis and abundance analysis works. These large grids offer excellent possibilities to explore the variation of the spectrum properties with stellar parameters. Even if theoretical stellar spectra modelling has greatly improved in the paste decades, the effects and the inconsistency introduced by the underlying simplifying assumptions still need to be analyzed in detail. Here a few comparison are shown, using broad band colors and direct spectra comparison. While (V-I) and (V-R) colors are a good reproduction of the empirical calibration for MARCS, Basel, A stars, (B-V) colors give a poorer result, being greatly affected by the well

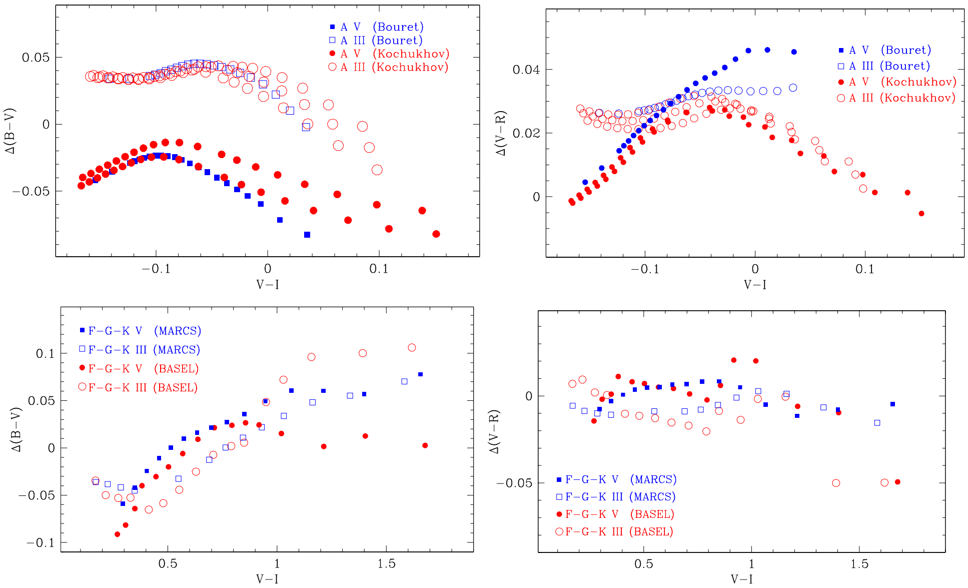

Fig. 2. Comparison in the (V-R)-(V-I) diagram among all available high resolution libraries covering the 8000÷15000 K $T_{\rm eff}$ range covered by A stars, for solar metallicity. Bottom panel shows difference between each library and the empirical calibration of Worthey & Lee (2006).

known problem of the line list. Direct spectra comparison shows that hot star spectra are in reasonable agreement. The differences between MARCS and PHOENIX are of the order of 10÷20%, in particular for cool stars and at the bluest end of the spectrum.

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