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Stars at high resolution: a library of synthetic spectra from 850 to 7000 Å

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Abstract. We present a new theoretical library of about 2500 high-resolution spectra of stars covering a wide wavelength range from 850 to 7000 Å. The set consists of an ultraviolet grid (1690 spectra), at an inverse resolution R=50 000, and an optical grid (832 spectra), at R=500 000, and spans a large volume in the fundamental parameters space (i.e. $T_{\rm eff}$, $log\, g$, [M/H]). The synthetic spectra, based on the ATLAS 9 model atmospheres, have been computed with the SYNTHE code developed by R.L. Kurucz. These properties make the library an updated tool, especially suitable to match high-quality observing data from the new-generation telescopes.

Key words. Stellar atmospheres – Stellar spectra

1. Introduction

Ten years ago, in May 1993, the first Keck telescope began the observations. It was the first of the new 8-10 meter class telescopes, that now populate several mountains around the globe. This outstanding step ahead in the observing effort was effectively backed up by improved optical capabilities of the telescopes and by the corresponding important advances in the performances of detectors and focus instruments.

In this regard, the new high-sensitivity spectrographs installed at the major telescopes are now providing data of unprecedented resolution and throughput quality even for the faintest objects in the Universe. For example, the Sloan Digital Sky Survey (SDSS) alone will produce about one million spectra of distant galaxies at an inverse resolution $R = \lambda/\Delta\lambda \sim 2000$.

In order to fully exploit the huge amount of information stored in these observations, it is mandatory to have theoretical tools of comparable resolution and accuracy made available (cf. Fig. 1). This is especially true for population synthesis techniques, that make extensive use of stellar libraries to model unresolved galaxies and match their integrated spectral energy distribution (SED).

Current reference libraries of stars for this task can either be empirical or theoretical. The latter present, however, some evident advantages over the empirical template sets: by definition, the atmosphere distinctive parameters [i.e. effective temperature ($T_{\rm eff}$), surface gravity (log g), and metallicity ([M/H])] are exactly

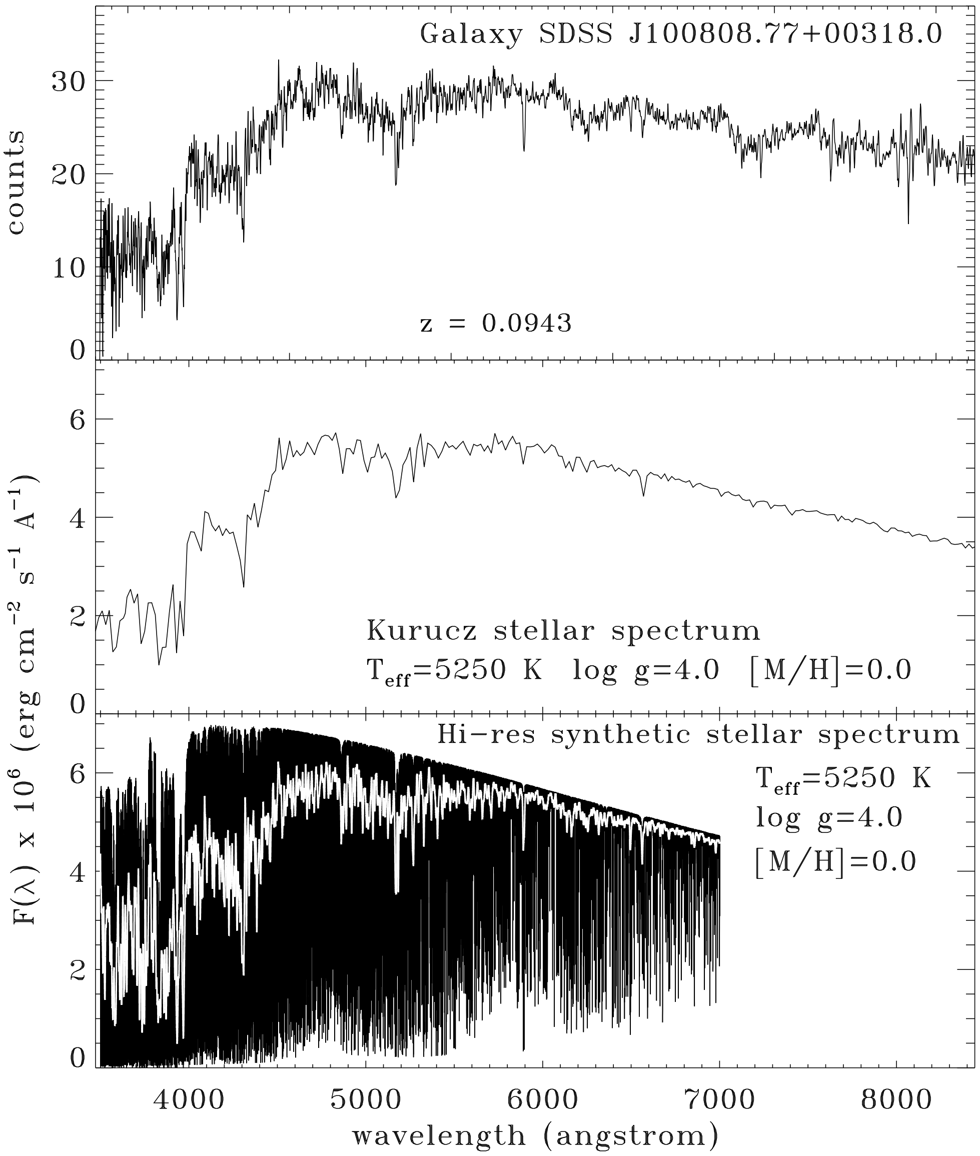

Fig. 1. *Upper panel*: the spectrum of a galaxy at redshift $z = 0.0943$ from the SDSS (wavelength scale has been shifted to the rest frame). The inverse spectral resolution is $R \sim 2000$. *Middle panel*: a stellar SED from the Kurucz (1993a) original library. This theoretical grid is one of the most used by astronomers. By comparing with the upper panel we see, however, that model resolution is not high enough as to match the observed data. *Lower panel*: an $R = 500,000$ stellar SED from our high-resolution library in the optical range, and its superposed broadened spectrum that reproduces the SDSS resolution.

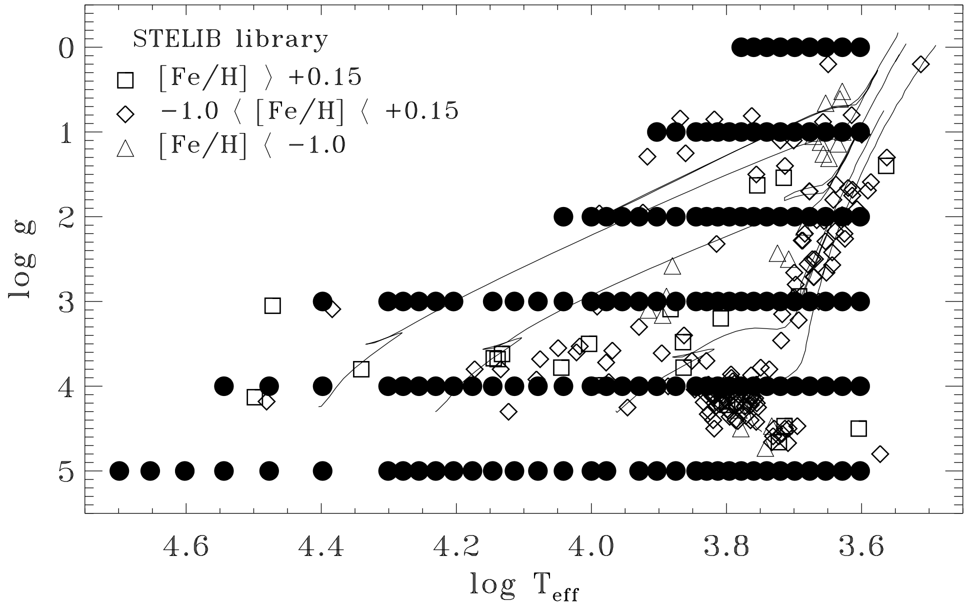

Fig. 2. Open markers show the distribution in the ($\log g$–$\log T_{\rm eff}$) plane of the stars in the recently released empirical library STELIB (Le Borgne et al. 2003). Solid circles are our optical grid of synthetic atmospheres for solar metallicity (a similar coverage is also assured for the full range of [Fe/H]). Solid curves are the Padova evolutionary tracks for stars of 1, 2, 5, and 10 $M_\odot$ (Girardi et al. 2000; Salasnich et al. 2000). The STELIB library consists of 257 objects and covers the wavelength range 3200–9500 Å with a resolution of 3 Å. Note however, that only 194 stars are reported to have a complete estimate of the atmosphere fundamental parameters.

known in the models, and the parameter space can be homogeneously covered (see Fig. 2). In particular, the latter point raises its importance at the extreme metallicity edges, i.e. far from solar, as both metal-poor and metal-rich stars cannot be properly sampled in the solar vicinity. In this line, with this contribution we want to introduce a new theoretical grid of high-resolution SEDs for stars in the UV-optical wavelength range. The library has been specifically conceived for population synthesis studies, but it can also be proficiently applied for abundance analysis in individual stars.

2. The high resolution synthetic library.

The full wavelength interval (850–7000 Å) for our models is covered by two distinct grids of synthetic spectra (one centered on the ultraviolet range, and the other tuned in the optical window). The UV and optical grids were computed separately and mainly differ in the spectral resolution, which is $R = 50\,000$ in the UV and $R = 500\,000$ in the optical, and in the grid sampling in the ($T_{\rm eff}$, $\log g$, $[M/H]$) parameter space, as summarized in Table 1. Both grids used as input the Kurucz ATLAS9 model atmospheres (Kurucz 1995) and consider a plane parallel geometry, local thermodynamic equilibrium, and a homogeneous chemical composition throughout the layers. Radiative and convective trasport are taken into account and the line blanketing, computed by means of opacity distribution functions (Kurucz 1979), includes the contribution of about 58 million atomic and diatomic molecular lines. The lack of polyatomic molecules makes however these models still inaccurate at low temperatures, below 3500 K, as for M and late K-type stars (cf. Kurucz 1992a).

Table 1. The main properties of the theoretical stellar library.

	UV grid	Optical grid
Wavelength range	850 → 4750 Å	3500 → 7000 Å
$R = \lambda/\Delta\lambda$	50 000	500 000
$T_{\rm eff}$	3000 → 50 000 K	4000 → 50 000 K
$\log g$	1.0 → 5.0	0.0 → 5.0
$[M/H]$	-2.0 → +0.5	-3.0 → +0.3
No. of spectra	1690	832

The high-resolution spectra were computed using the SYNTHE series of codes by Kurucz (1993b). Line opacity derives from the huge database of Kurucz (1992b), that include all atomic elements at different ionization states and several diatomic molecules (namely, C_2, CN, CO, CH, NH, OH, MgH SiH, H_2, and SiO).

As a major improvement, in our spectra we also accounted in some detail for the TiO contribution, relying on the updated work by Schwenke (1998). This new line database provides a more accurate description of the band absorption in the optical range. Quite importantly, the TiO molecule reveals to be a main absorber in the atmosphere of M and late-K stars, and it can strongly affect the continuum region around the 5170 Å MgH feature. This has a direct impact when computing Lick spectrophotometric indices, such as Mg_2 (Trager et al. 1998), from theoretical spectra. In this sense, our preliminary analysis shows that substantial discrepancies can be introduced in the theoretical calibration of the main spectral features in the optical range if the TiO contribution is neglected or not properly accounted for in the calculations (Bertone 2002).

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