Comparative analysis of modern empirical spectrophotometric atlases with multicolor photometric catalogues

E. Yu. Kilpio1*, O. Yu. Malkov1,2, and A. V. Mironov3
1Institute of Astronomy, Russian Acad. Sci., 48 Pyatnitskaya, Moscow 119017, Russia
2Faculty of Physics, Moscow State University, Leninskie Gory, Moscow 119991 GSP-1, Russia
3Sternberg Astronomical Institute, Moscow State Univ., 13 Universitetskij Prosp., Moscow 119992, Russia

Received 2nd May 2014

Abstract.

We present the results of the comparative analysis of the most known semi-empirical and empirical spectral atlases that was carried out using the data from the WBVR photometric catalogue. The results show that standard error of synthesized stellar magnitudes calculated with SEDs from best spectral atlases reaches 0.02 mag. It has been also found out that some of modern spectral atlases are burdened with significant systematic errors. The agreement for the 5000-10000 A spectral range is rather satisfactory, while there are problems for wavelengths shorter than 4400 A.

Keywords: semiempirical atlases – catalogues – stars: fundamental parameters

1. Introduction

For a great variety of astrophysical applications it is extremely important to know (at least relative) spectral energy distribution (SED) for

• as many stars as possible, and
• as many types of stars as possible.

* By Elena Kilpio, email: lena@inasan.ru
† email: lena@inasan.ru
Semi-empirical spectrophotometric atlases are designed to meet the latter requirement, meanwhile to satisfy the former one a large number of empirical atlases are constructed.

The Asiago Database of Spectroscopic Databases (Sordo & Munari, 2006) includes about 300 empirical stellar spectral atlases, published from the late sixties to 2005. The majority of them covers a very restricted spectral range or/and contains too small number of stars. Less than a dozen of atlases contain large enough number of objects (at least hundreds) and provide SEDs for spectral range of at least 3000-9000 Å. Among them are Pulkovo Spectrophotometric Catalogue, Alma-Ata atlas, NGSL, ISO-SWS atlas and some others. However, a comparison of data from these atlases for common stars shows numerous and significant disagreements, especially for UV spectral range.

On the other hand, multicolor high-precision photometry for much larger number of stars is available in different photometric systems. The most precise photometry can be found in Hipparcos/Tycho-2 catalogues and in ground-based WBVR catalogue of northern stars. So, the reliability of data in stellar spectral atlases can be checked by a comparison of magnitudes, calculated with methods of synthetic photometry, with catalogued data.

Here we present the results obtained using the observational data from the Catalogue of WBVR magnitudes of Bright Northern Stars (Kornilov et al. 1991). This catalogue provides the four-colour WBVR photoelectric magnitudes for 13586 northern sky objects (δ > −15) obtained at the high-altitude observatory in Kazakhstan using a four-channel photometer attached to the 0.5m reflector. The mean error in V (σV) for nonvariable stars in the catalogue is 0.003m. Limiting stellar magnitude is V = 7.2m. The catalogue is complete up to V = 7m. The WBVR catalogue can be considered as a photometric catalogue of Hipparcos level accuracy.

2. Semi-empirical atlases

Only two of semi-empirical atlases among those contained in The Asiago Database cover rather wide spectral range: Sviderskiene (1988) (1200-10500 Å) and Pickles 1998 (1150-25000 Å). The semi-empirical stellar spectral atlas of Pickles (1998) is widely used and remains one of the best spectral atlases, however, as our analysis shows, synthetic magnitudes calculated with Pickles data appreciably differ from observed ones for some types of stars. Particularly (see Fig.1), B,V,R magnitudes of K4 and later giants predicted by Pickles (1998), deviate significantly from ones listed in WBVR catalogue (Kornilov et al. 1991) while the data from Sviderskiene (1988) fit them better.

It should be noted also (see Fig.2) that data for O-type stars in the Pickles (1998) atlas are not corrected for interstellar extinction carefully or specifically enough. Pickles curve reproduces a SED for the faint, presumable reddened HD 48279, while Sviderskiene (1988) data show a good agreement with the brighter, presumably unreddened HD 47839.
Figure 1. Synthetic B,V,R photometry, calculated from Pickles (1998) and Sviderskiene (1988) data for red giants, together with observational data from WBVR catalogue (Kornilov et al. 1991).

Figure 2. Data for O5V type star according to Pickles (1998) and Sviderskiene (1988). Spectra of two real O type stars are also given.
3. Empirical spectral atlases

Early empirical atlases (e.g., Breger (1976), Gunn and Stryker (1983)) contained few hundreds of stars. In late 80th more representative atlases came up to take their place: Spectrophotometric Catalogue of Stars (hereafter SCS) by Kharitonov et al. (1988), Sternberg Spectrophotometric Catalog by Glushneva et al. (1982-1984) with its IR extension Moscow Spectrophotometric Catalog by Glushneva et al. (1980-1991). The most precise data on 238 secondary spectrophotometric standards (hereafter SSS) were collected by Glushneva et al. (1992). Pulkovo Spectrophotometric Catalog published by Alekseeva et al. (1996, 1997) should also be mentioned among the most representative and precise spectrophotometric catalogues.

From the Asiago Database (Sordo & Munari 2006) we selected those atlases of observed stellar spectra that contained enough stars and provided the data in wide spectral range. These atlases are listed in Table 1 (together with some earlier atlases) and shown in Fig.3

Figures 4-5 illustrate rather typical results of comparison of atlases. It should be noted that data presented in various atlases often significantly differ even for bright stars,
Figure 4. Spectral energy distribution of HD 87737 (upper panel) and α Leo (lower panel), presented in various atlases. Curves are normalized at 5500 Å. Both stars are located at high galactic latitudes and both are not distant ones so the differences between atlases we see here can not be explained as the effect of interstellar extinction.
Table 1. Empirical spectral atlases

| Name            | No of stars | Spectral range       | Reference                                      |
|-----------------|-------------|----------------------|------------------------------------------------|
| ELODIE 3.2      | 1388        | 3900-6800            | Wu et al. (2011)                               |
|                 |             |                      | http://www.obs.u-bordeaux1.fr/m2a/soubiran/elodie_library.html |
| Indo-US / CFLIB | 1273        | 3460-9464            | Valdes et al. (2004)                           |
|                 |             |                      | http://www.noao.edu/cflib/                     |
| MILES 9.1       | 985         | 3525-7500            | Falcon-Barroso et al. (2011)                   |
|                 | 706         | 8350-9020            |                                               |
|                 |             |                      | http://miles.iac.es                            |
| NGSL 2          | 374         | 1670-10250           | Heap and Lindler (2007)                        |
|                 |             |                      | http://archive.stsci.edu/prepds/stisngsl/      |
| STELIB 3.2      | 249         | 3200-9500            | Le Borgne et al. (2003)                        |
|                 |             |                      | http://webast.ast.obs-mip.fr/stelib            |
| UVES POP        | 359         | 3000-10000           | Bagmulo et al. (2003)                          |
|                 |             |                      | http://www.sc.eso.org/santiago/uvespop/        |
| SCS             | 1147        | 3225-7575            | Kharitonov et al. (1988, 2011)                 |
|                 |             |                      | VizieR: III/202                                |
| SSS             | 238         | 3200-7600            | Glushneva et al. (1992)                        |
|                 | 99          | 6000-10800           |                                                |
|                 |             |                      | VizieR: J/A+AS/92/1                            |
| Pulkovo         | 679         | 3200-7350            | Alekseeva et al. (1996, 1997)                  |
|                 | 278         | 3200-10800           |                                                |
|                 |             |                      | VizieR: III/201                                |

1 885 stars cover the indicated spectral range, SEDs of other stars have gaps.
2 SEDs of some stars have gaps.
3 ...of the preceding number of stars.

especially in the UV range. Here one more effect can be also seen - sometimes there is bad sewing between wavelength ranges in UVES-POP (see Fig.1).

Synthetic magnitudes and colors can be calculated for stars, presented in empirical atlases, combining their spectral energy distributions with response curves. Such magnitudes and colors in WBVR system were calculated for stars, catalogued in (Kornilov et al. 1991) and included in the atlases. Results of comparison for various spectrophotometric atlases are presented in Table 2.

Preliminary analysis of modern empirical spectral atlases shows the following.

- Accuracy of the ground-based SSS and of the space-born NGSL atlases is comparable. Standard error of synthetic photometry, calculated from the two SEDs, reaches 0.02.
Figure 5. $\alpha$ Leo: the detailed view of the area marked in Fig 4 by the yellow rectangle is shown in details to illustrate the example of bad sewing between two spectral ranges in UVES-POP.

Table 2. Comparison of synthetic and cataloged (Kornilov et al. 1991) colors

|       | UVES-POP | STELIB | MILES | Indo-US | NGSL | SSS |
|-------|----------|--------|-------|---------|------|-----|
| $\sigma_{W-B}$ | 0.043    | 0.118  | 0.192 | 0.210   | 0.028| 0.072 |
| No of stars     | 7        | 13     | 34    | 76    | 15  | 231 |
| $\sigma_{B-V}$  | 0.015    | 0.093  | 0.113 | 0.087   | 0.018| 0.020 |
| No of stars     | 6        | 11     | 34    | 76    | 15  | 231 |

- The UVES-POP atlas is precise enough, however, sometimes different spectral ranges are not sewed accurately.
- Systematic errors of the other atlases are significant (more than 0.01).
- Spectrum calibration problems in the UV spectral range remain unsolved.

4. Conclusions

The comparative analysis of the most popular semi-empirical and empirical spectral atlases has been carried out using the data from WBVR photometric catalogue. Basing on the results of this analysis we can make the following conclusions:

- Standard error of synthesized stellar magnitudes, calculated with SEDs from best spectral atlases, reaches 0.02 mag.
Some of modern spectral atlases are burdened with significant systematic errors.

SEDs from majority of atlases show satisfactory agreement for the 5000-10000 Å spectral range, but problems for wavelength shorter than 4400 Å remain.

Acknowledgements

This work has been supported by Russian Foundation for Basic Research grants 09-02-00520, 10-07-00342 and 10-02-00426, by the Federal Science and Innovations Agency under contract 02.740.11.0247, by the Federal target-oriented program “Scientific and pedagogical staff for innovation Russia” (contract No. P1195), and by the Presidium RAS program “Leading Scientific Schools Support” 4354.2008.2. This research has made use of NASA’s Astrophysics Data System Bibliographic Services (ADS).

References

Alekseeva G. A., Arkharov A. A., Galkin V. D. et al. 1996, Baltic Astronomy 5, 603; 1997, Baltic Astronomy 6, 481
Bagnulo S., Jehin E., Ledoux C. et al. 2003, Messenger, 114, 10
Breger M. 1976, ApJS, 32, 7
Falcon-Barroso J., Sanchez-Blazquez P., Vazdekis A. et al. Astron. Astrophys. 532, id.A95
Glushneva I.N., Doroshenko V.T., Fetisova T.S. et al. 1980, Soobsh.Gos. Astron. Inst. Shternberga 219;3;1980, Astron. Zh. 57,1003;1982, Trudy Gos.Astron.Inst. Shternberga 52, 182; 1983, Trudy Gos.Astron.Inst.Shternberga 55, 84;1989, Trudy Gos.Astron.Inst.Shternberga 61, 272;1991, Trudy Gos.Astron.Inst. Shternberga 62,119
Glushneva I.N., Doroshenko V.T., Fetisova T.S. et al. 1982, Spectrophotometry of Bright Stars (ed. Glushneva I. N.) Moscow, Nauka, pp.3-252; 1983, Trudy Gos. Astron. Inst. Shternberga 53, 50; 1984, Trudy Gos. Astron. Inst. Shternberga 54, 3
Glushneva I. N., Kharitonov A. V., Kniazeva L. N, Shenavrin, V. I. 1992, Astron. Astrophys. Suppl. Ser., 92, 1
Gunn J. E., Stryker L. L. 1983, ApJS 52, 121
Heap S. R., Lindler, D. J. 2007, ASPC 374, 409
Kharitonov A. V., Tereshchenko V. M. and Knyazeva L. N. 1988, Alma-Ata, Nauka, p. 484; recent 3rd edition: 2011, Spectrophotometric Catalogue of Stars (ed. Tereshchenko V. M.) AlmaAty, Kazakh. Univ., pp.4-304
Kornilov V.G., Volkov I.M. et al. Catalogue of WBVR magnitudes of Bright Northern Stars, Ed.-in-Chief Kornilov V.G., M.: Moscow State Univ. Pubbl., 1991
Le Borgne J.-F., Bruzual G., Pello R. et al. 2003, A&A 402, 433
Pickles A.J. 1998, Publ. Astron. Soc. Pac. 110, 863
Sordo R., Munari U. 2006, A&A 452, 735
Sviderskiene Z. 1988, Vilnius Obs. Bull. 80, 3
Valdes F., Gupta R., Rose J. A. et al. 2004, Astrop. J. Suppl. 152, 251
Wu Y., Singh H. P., Prugniel P. et al. 2011, A&A, 525, A71