A World Wide Web Tool for Spectrophotometric Standard Stars

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1. Importance of Spectrophotometric Standards

Spectrophotometric standards play a vital role in all aspects of astronomical spectroscopy, independent of the type of objects observed and the spectral resolution. The role of a spectrophotometric standard is to correct for the wavelength-dependent sensitivity of the atmosphere + telescope + spectrograph + detector combination and to provide the absolute zero points of the flux (or magnitude) scale. Without standards, accurate astrophysical diagnostic line ratios cannot be determined, spectral energy distributions cannot be computed and matching of spectra from other wavelength bands (UV, IR, radio) cannot be accomplished, for example. In addition, the provision of spectrophotometric standards enables (photometric) calibration of narrow band imaging data.

To be useful, spectrophotometric standards should satisfy the following criteria:

- be bright (but not too bright that shutter timing or shading at very short exposure times are a source of error)
- be single stars
- have a spectral energy distribution which is 'flat' with wavelength, or at least does not have too many narrow features
- have a sufficient density of flux measurements with wavelength to allow effective calibration of even high-resolution spectra
- be well distributed on the sky so that airmass corrections between the standard and the target are not large.

Of course, no set of stars could be found to satisfy all these criteria. A range of brightness is preferable so that the standards can be used on large and small telescopes and at a range of spectral dispersions. If there are close companions to the stars they should be much fainter and not very much different in colour to minimise calibration uncertainties. There is of course no stellar source with a flat (F_λ or F_ν = constant) spectrum. White dwarfs come closest to being the ideal real standard since they have few lines, and these are usually weak. If the standards have absorption lines they should be broad rather than narrow, otherwise the detected flux at the centre of the lines can critically depend on the spectral resolution. If the standard star fluxes are tabulated at wide wavelength intervals, then spurious features are typically seen at the positions of these absorption lines in the calibrated target spectrum. Providing excellent standard stars with a high density of flux measurements is a long and time-consuming process; there is clearly a compromise between having many standards over the sky and requiring a correction for the different airmass of the target and standard. Currently most standards are within about 30° of any target.

2. Available Spectrophotometric Standards

The best-known set of optical spectrophotometric standards is that of Oke (1974). These are white dwarf standards observed with the Palomar multichannel spectrometer and having a wavelength coverage from about 3300 to 10000 Å. Oke listed fluxes for 38 stars with bandpasses from 20–80 Å in the blue and 40–360 Å in the red. However, these stars were never intended as standards in the accepted sense, but for comparison of the absolute spectral energy distribution of white dwarfs with models. In collaboration with the HST project, which had foreseen the need for UV-optical standards to enable calibration of the Faint-Object Spectrograph and the Goddard High-Resolution Spectrograph, Oke (1990) published uniform data for 25 stars from 3200 to 10200 Å with flux determinations every 1 Å in the blue and 2 Å in the red. These data, taken with the Hale double-beam spectrograph, were combined with IUE and Voyager observations to yield a set of HST spectrophotometric standards (Turnshek et al., 1990; Bohlin et al.,

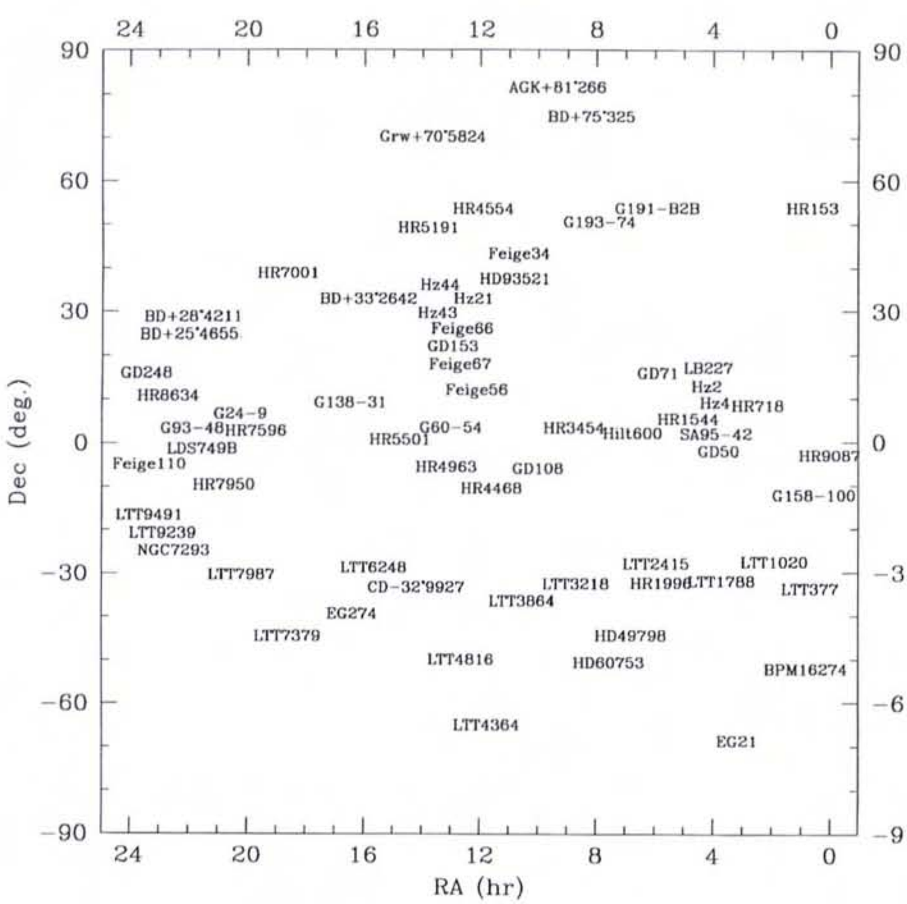
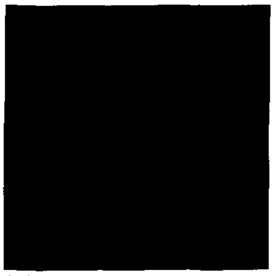


Figure 1: An RA-Dec sky map of the positions of the HST, Oke (1990) and CTIO standard stars. In the WWW tool, clicking at the position of one of the standards brings up a page of details on that particular standard (see Figure 2).

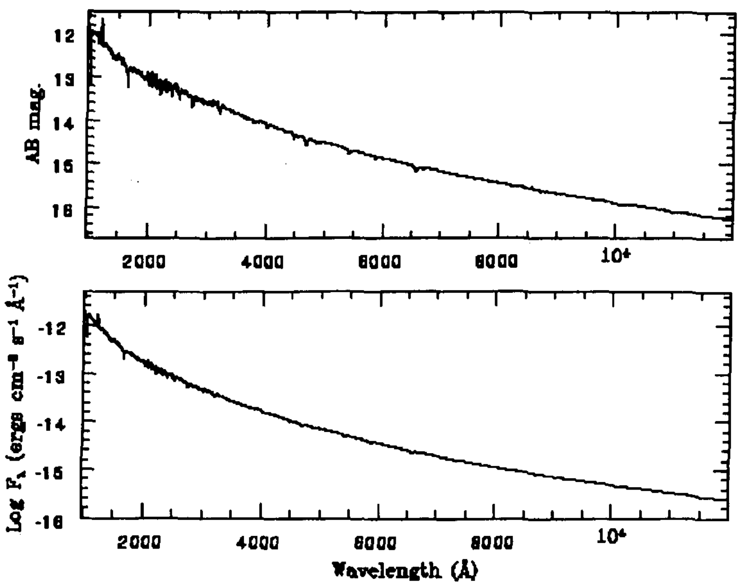
Hz 21

alpha(2000) = 12h 13m 56.42s , delta(2000) = +32d 56' 30.8"

V = 14.69, B–V = –0.33, Spectral type: DO2



Field is 10.0 x 10.0 arcmin



Oke (1990) data; IUE + Model data

ftp access to visible wavelength data files for this standard

ftp access to UV+visible wavelength data files for this standard

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Figure 2: An example 'page' for the standard star Hz 21 taken from the WWW tool.

1990). The V magnitudes synthesised from the Oke data, however, show small offsets from photometric data by 0.03 mag. on average. The Oke (1990) narrow-band magnitudes should therefore be corrected as detailed by Colina & Bohlin (1994).

The Hubble Space Telescope Faint-Object Spectrograph (FOS) has a continuous wavelength coverage from 1140 to 9200 Å at a resolution of ~ 1300, so it is an ideal instrument for spectroscopy of standard stars. Comparison of FOS spectra with model atmospheres however showed some discrepancies in the UV, suggesting that the absolute flux measurements in the UV were not reliable. White-dwarf models have now reached a degree of reliability that they can be used to provide the true flux distributions for standard stars. Bohlin & Colina (1995) (see also Bohlin, 1995) have begun publishing a set of primary white-dwarf spectrophotometric standards which should provide the fundamental basis for calibration. The absolute fluxes are reliable to about 1% and the relative fluxes should be good to about 2%. Eight primary standards are used and FOS observations of another 18 stars provide secondary standards. These stars are of intermediate brightness (V = 9–16 mag.), so are ideal as spectrophotometric standards for large telescopes.

The Oke (1974 and 1990) standards were observed from Palomar and so are restricted to northern declinations and the equatorial region (the most southerly is at $\delta = -21°$). For observation in the south there were standards established by Stone & Baldwin (1983). However, these standards were only tabulated at rather wide wavelength intervals, so were of limited use for work at higher resolution. The CTIO group have re-observed these standards and provide flux measurements at 50 Å intervals from 3300 to 10000 Å for 19 stars. In establishing the absolute magnitudes of these standards they used a set of 11 bright equatorial standards taken from Taylor (1984). Since Vega is the primary standard (Hayes & Latham, 1975) these are secondary standards, and the southern Stone and Baldwin standards therefore tertiary standards. Their spectral type is rather varied with few white dwarfs.

3. A WWW Tool

In 1992 I produced a booklet giving finding charts and magnitude and flux vs. wavelength plots for the Oke (1990) standards and the HST standards (a total of 40 stars). This was distributed to observatories and interested individuals (Walsh, 1993). I have subsequently developed this booklet into a tool on the World Wide Web to allow easy access to information on the standards and their flux distributions. So far the Oke (1990) data, the old HST standards, the primary WD standards (Bohlin, 1995) and the Hamuy et al. (1992, 1994) secondary and tertiary standards have been included (69 stars in total). The aim of the tool is to allow easy access to the standard star data with the observing astronomer in mind. Co-ordinates and finding charts are given and the position of the nearest standard is available on a map. By viewing the flux data for a standard, the astronomer can then quickly decide which is the best standard to use for effective and accurate calibration of the target spectrum. The URL is:

http: //www.eso.org/ spect-phot-standards/ optuvstandards.html

The first page of the tool is an introduction which allows brief details of the sources of the data to be viewed. Access to the information on each standard is by two routes: an RA ordered list giving also spectral type and magnitude; a clickable sky map. Figure 1 shows the disposition of all the standards on an RA-Dec plot as used in the WWW tool. There are some regions of the sky which are over-represented by standards and others at high declinations which are under-represented. From either of these entry points, the user arrives at a page for each standard containing the co-ordinates, magnitude and colour, a finding chart and plots of F_λ and AB mag. vs. wavelength. Figure 2 shows a typical such 'page' for the standard star Hz 21. The finding charts for each standard are produced either from publications or from the Digital Sky Survey. The epoch of these images is mostly that of the original Palomar Sky Survey or Southern Sky survey. A number of the stars have large proper motions so that up-to-date images would be preferred. [I would welcome images from other sources (e.g. EFOSC or EMMI acquisition images) to replace these finding charts.] The standard star data are usually tabulated as narrow band magnitudes, and in converting the monochromatic AB magnitudes to flux the definition:

$$\text{AB mag} = -2.5 \times \log_{10}(F_\nu) - 48.59$$

(e.g. Hamuy et al., 1992) was used.

Each standard star 'page' also carries clickable entries to the ST-ECF anonymous ftp account where the data are held. For each star and data source (some stars are covered by more than one set of measurements), there are ASCII files of the AB magnitude vs. wavelength and flux (ergs cm^{-2} s^{-1} $Å^{-1}$ and ergs cm^{-2} s^{-1} Hz^{-1}) vs. wavelength. Depending on the data reduction system used, AB mag. or flux (F_λ or F_ν) is required. There is a readme file in each directory of the anonymous ftp account describing the contents. In addition there is a MIDAS command file to convert all the ASCII (flux) files in each directory into MIDAS tables. Clicking from the standard star 'page' to the ftp area moves to the appropriate directory, rather than opening a single file. In each directory there are two files for each star (one for magnitudes, one for fluxes) and there may be other files in another ftp directory for the same star. The user must exercise some judgement here – the data retrieved depend somewhat on the application.

4. Prospects

The WWW provides an ideal method of access to such data and the observing astronomer can display the output on the same screen as the data-viewing tool. It should enable observers to select the most suitable spectrophotometric standard appropriate to their particular observation. When service observing (or queue scheduling) is implemented, the spectrophotometric standard may be automatically chosen. However there are a number of considerations to address in choosing the 'best' standard, as I have emphasised. There should also be allowance for user preference, for example when it is found that a particular standard with a particular instrument combination always gives a consistent value for the Balmer decrement.

Even if an astronomical instrument is internally well calibrated, observation of spectrophotometric standards is still required. The atmosphere, even at optical wavelengths, has time-varying emission and transmission properties, necessitating at minimum zero point calibration. The presence of water vapour, cloud and dust can give a wavelength-dependent atmospheric extinction, which can only be corrected by a calibrator above the atmosphere. Thus ground-based pipeline calibration must always make allowance for night-to-night variations in a way not needed by orbiting telescopes. Good sky coverage by high quality spectrophotometric standards will thus remain a necessity.

I would welcome comments on this tool and in particular suggestions for additional standards to include.

Thanks

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Planning for La Silla in the VLT Era: What Came Out?

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As readers will be aware, an ESO Working Group has been engaged in charting the future of the La Silla observatory at the time when it will operate jointly with the VLT. The final (6th) version of the report of the WG was presented to Council and the Director General at the Council meeting in Milan in November 1995. Thus, it is now part of ESO's mid- and long-range scientific and technical planning and available as document ESO/STC-174 rev. (22 Nov. 1995) and from the ESO WWW home page.

Earlier articles (*The Messenger* **78**, 3 and **80**, 4) have described the charge and composition of the Working Group and the procedures it adopted to involve the views and ideas of the community in the preparation of its plan. These included a questionnaire survey of the entire community and discussions of drafts of the plan with the ESO committees in several iterations. The input of the OPC on the scientific aspects was especially appreciated.

Colleagues interested in the detailed recommendations of the WG are advised to consult the report itself. Here, I should like to share with readers a few general points, especially such as have emerged in the discussions over the last few months. I should also like, on behalf of the WG, to thank the many colleagues inside and outside ESO who have contributed to making the report as comprehensive and thorough as possible.

The Impact of the VLT

The VLT will not be an exclusive toy, reserved for a small elite: With a number of foci exceeding the total number of telescopes on La Silla and a collecting area some seven times as large, the VLT will make a major impact on virtually all sections of ESO's user community.

Hence, already for scientific reasons *per se*, La Silla and other observatories with 1–4-m class telescopes will not be conducting "business as usual" in the VLT era. While all analyses show that a broad complement of such intermediate-size facilities will continue to be needed, their work will be largely conditioned by the research done at the 8-m giants, and their tasks then will be different from now. It is therefore appropriate for the community to begin preparing its scientific plans for the use of intermediate-size telescopes in the VLT era, and for ESO to begin preparing to provide the facilities that will be needed.

Future Needs for Intermediate-Size Telescopes

Many of the projected highest-priority uses of intermediate-size telescopes in