A Comparison of EUVE Fluxes with Absolute Stellar Calibration at Longer Wavelengths

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Abstract. We use archive spacecraft data together with ground-based spectral data to establish a set of spectrophotometric stars and corresponding model atmospheres, which can be used to self-consistently define absolute stellar fluxes over the entire wavelength range from 100 Å to 10,000 Å. Present calibration standards, while largely adequate longward of 1200 Å are used in an inconsistent fashion by different instruments in different bands. At shorter wavelengths, very several advantages can be made in the definition of the absolute fluxes of standard stars. The basis of our effort involves a set of seven hot pure-hydrogen white dwarfs spanning the temperature range from 20,000 K to 50,000 K. This set of stars offers substantial improvements over the way standard stars have been used in the past to define absolute fluxes. A set of stars, each defined by a self-consistent model atmosphere, is used for virtually all wavelengths, thus establishing a well-defined relationship between fluxes from different instruments in different wavelength bands. A considerable effort is made to establish that these stars are free as possible of confounding factors such as unseen companions, interstellar reddening, or unmeasured ISM or circumstellar absorption.

1. Introduction

As part of an ongoing NASA Astrophysics Data Analysis program we present the preliminary results of a direct comparison of the absolute fluxes for six hot white dwarfs observed spectroscopically with EUVE with the absolute fluxes of the same stars at longer wavelengths in the Far UV, UV, and the optical. The ultimate goal of this program is to unambiguously link the absolute flux scales, at all wavelengths, by using a common set of standard stars and a consistent set of model stellar atmospheres.
2. The Standard Stars

An initial set of seven DA white dwarfs, covering the effective temperature range 20,000 to 50,000 K were selected as primary standard stars. These stars were selected to meet the following criteria:

- As wide a range of effective temperature as possible;
- Little or no heavy element content;
- Relative low interstellar columns and strong EUV continuum fluxes;
- Wide range of existing observations at wavelengths from the EUV to the IR;
- Good observational history with few confounding factors such as close companions, ISM reddening.

In Table 1, we list the stellar parameters for our seven primary standards. The visual magnitudes, effective temperatures and surface gravities are weighted averages taken from the literature. In Table 2, we provide the observed ISM column densities for the species H I, He I and He II for the six of our stars for which EUVE spectra exist. The ISM columns come from several sources including the analysis of the EUVE spectra for each star from Barstow et al. (1997), Dobbie (2000) and Holberg et al. (1995). Where possible, we have used determinations of the H I columns from the analysis of the cores of the stellar Lyman $\alpha$ profiles from HST (Sahu, 2001 private communication, and Holberg et al. 1999) which are independent of EUV determinations. In general, the Lyman alpha, H I column densities are found to be in excellent agreement with the estimates obtained from EUVE.

<table>
<thead>
<tr>
<th>Star</th>
<th>d(pc)</th>
<th>V$\text{mag}$</th>
<th>T$\text{eff}$</th>
<th>log g</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZ 43</td>
<td>68</td>
<td>12.914</td>
<td>50,515(56)</td>
<td>7.964(0.034)</td>
</tr>
<tr>
<td>GD 153</td>
<td>73</td>
<td>13.352</td>
<td>39,158(90)</td>
<td>7.770(0.013)</td>
</tr>
<tr>
<td>GD 659</td>
<td>58</td>
<td>13.360</td>
<td>35,326(78)</td>
<td>7.923(0.014)</td>
</tr>
<tr>
<td>GD 71</td>
<td>49</td>
<td>13.023</td>
<td>32,843(71)</td>
<td>7.783(0.016)</td>
</tr>
<tr>
<td>Lanning 18</td>
<td>42</td>
<td>12.950</td>
<td>29,420(56)</td>
<td>7.819(0.017)</td>
</tr>
<tr>
<td>CD -38°10980</td>
<td>13</td>
<td>10.990</td>
<td>24,537(112)</td>
<td>8.069(0.023)</td>
</tr>
<tr>
<td>Wolf 1346</td>
<td>15</td>
<td>11.530</td>
<td>19,933(35)</td>
<td>7.836(0.007)</td>
</tr>
</tbody>
</table>

In Fig 1. we show a comparison of the observed EUVE fluxes for HZ 43 with both those obtained from the HST Faint Object Spectrograph (FOS, Bohlin et al. 1995), Orfeus 2 (Dupuis et al. 1998) and the model atmosphere fluxes defined for a model with the parameters given in Tables 1 and 2.
Figure 1. A direct comparison of the absolute fluxes for HZ 43 from FOS (red), Orfeus 2 (blue) and EUVE (purple). Also shown is the stellar model atmosphere described in the text.

Table 2. ISM Column Densities ($x 10^{18}$ cm$^{-2}$)

<table>
<thead>
<tr>
<th>Star</th>
<th>$N_{HI}$</th>
<th>$N_{HeI}$</th>
<th>$N_{HeII}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZ 43</td>
<td>0.815±0.02</td>
<td>0.065±0.004</td>
<td>0.016</td>
</tr>
<tr>
<td>GD 153</td>
<td>0.767±0.02</td>
<td>0.069±0.005</td>
<td>0.006</td>
</tr>
<tr>
<td>GD 659</td>
<td>3.20±0.82</td>
<td>0.214±0.077</td>
<td>0.049</td>
</tr>
<tr>
<td>GD 71</td>
<td>0.69±0.04</td>
<td>0.022±0.007</td>
<td>0.000</td>
</tr>
<tr>
<td>Lanning 18</td>
<td>1.97±3.06</td>
<td>0.00±0.271</td>
<td>0.238</td>
</tr>
<tr>
<td>CD-38°10980</td>
<td>18.094±0.010</td>
<td>0.000±0.382</td>
<td>0.00</td>
</tr>
</tbody>
</table>

3. The EUVE Data

The EUVE spectra for each of our stars were obtained from the EUVE archives by J. Dupuis. Fluxes were extracted using the most recent calibration files and in most cases represent the coaddition of all useful existing spectra. For several stars such as HZ 43 and GD 153, these data sets are the same as those being used to establish the final EUVE absolute calibration. Individual spectra from the short, medium, and long wavelength spectrometers have been merged and concatenated into a single spectrum.
4. The Stellar Models

For this comparison, we have used models interpolated from a grid of LTE, pure-hydrogen model stellar atmospheres produced by TLUSTY (Hubeny et al. 1985). This grid incorporates the most recent corrections derived from detailed comparisons with the independent modeling programs of Koester and Bergeron. Detailed comparisons of the EUVE observations will be made with both LTE and NLTE models.

5. Results

In Figures 2 - 7 we show the results of direct comparisons of the predicted model fluxes and the EUVE observations for six of the seven standard stars. The seventh star, Wolf 1346, is too cool to have a significant EUV flux. In each case no adjustments have been made to fit the EUVE data. The temperatures and gravities are derived spectroscopically from the analysis of the Balmer line profiles and the fluxes have been normalized to the V magnitude. The ISM absorptions applied to each model, including continuum and line opacities, are those described in Table 2. Thus for each star, the models closely match the observed fluxes at wavelengths longward of the Lyman limit. As seen in the example shown in Fig. 1, the strategy for defining the final set of model fluxes will be to adjust the model parameters within the range allowed by the Balmer line and Lyman line data and seek to determine a common ‘best-fitting’ flux scale which is not dependant on the flux from any individual star and relatively independent of stellar effective temperature. The final result will be a single set of model fluxes which are consistent with the observed fluxes and bear a known, well-defined relationship to the observed fluxes of each star in all bands. This system of calibrated fluxes will then be extended to incorporate important secondary standard stars such as G191-B2B and BD +28° 4211, which are not as easily modeled as the DA white dwarf primary standard stars.

6. Conclusions

In general, the agreement is excellent for all stars. Except at the very longest wavelengths, (λ > 600 Å), the EUVE flux calibration agrees within 10% with the model predictions. There are however, some systematic wavelength dependent deviations which will be investigated. In the future we will fit the EUVE spectra, within the narrow bounds of the stellar parameters allowed by the Balmer and Lyman observations and the interstellar HI columns allowed by the STIS Lyman α spectra.
Figure 2. HZ 43. Comparisons of the predicted model fluxes with the observed EUVE fluxes for six DA white dwarfs. The residual (observed - model) fluxes are shown below on a log scale.

Figure 3. Gd 153
Figure 4. GD 659

Figure 5. GD 71
Figure 6. CD -38° 10980

Figure 7. Lanning 18
7. Acknowledgments

This work has been supported in part by NASA Grant NAG5-981.

References