Baltic Astronomy, vol. 15, 123–126, 2006.

ATMOSPHERIC PARAMETERS FOR SUBDWARF B STARS: A CONSISTENCY CHECK BETWEEN THE BALMER LINES AND THE FAR-ULTRAVIOLET SPECTRUM

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Received 2005 August 1

Abstract. The use of Balmer line profiles to determine atmospheric parameters of subdwarf B stars is a well-established method that relies on a comparison of spectroscopic observations with synthetic spectra generated from model atmospheres. This method allows us to determine parameters such as the effective temperature, surface gravity and photospheric helium abundance. The self-consistency of these parameters can be investigated by examining the Lyman lines covered by current far-ultraviolet observations. We discuss the results of a preliminary analysis of a sample of ten subdwarf B stars for which both optical and far-ultraviolet spectra were secured. At temperatures below 30 000 K we find good consistency between optical and ultraviolet spectra when some allowance is made for the metal-line blanketing present in the ultraviolet region. At higher effective temperatures, however, the consistency is not as satisfactory. Possible solutions to this puzzle are considered.

Key words: stars: atmospheres, subdwarfs

1. INTRODUCTION

The atmospheric parameters which characterize the subdwarf B (or sdB) stars are now routinely obtained from simultaneous fits to the Balmer line profiles with synthetic spectra generated from model atmospheres (see, e.g., Saffer et al. 1994). Over the years, this method has proved quite reliable, although systematic effects between various grids of models may still be present. The method can, in principle, be extended to the Lyman region of the spectrum, just as it has been for the DA (Barstow et al. 2001, 2003) and DAO white dwarfs (Good et al. 2004). However, in the case of the hot B subdwarfs, it is expected that the interpretation of the fits to the Lyman lines might be more complicated, since the far ultraviolet spectra of sdB stars are known to include hundreds of transitions from heavy elements (see, e.g., Ohl et al. 2000). The blocking effect of these numerous lines would have to be considered in any fit purporting to match the ultraviolet continuum level of hot B subdwarfs. This problem could be solved by fitting the ultraviolet continuum with fully blanketed synthetic spectra; however, this cannot be accomplished in a routine manner yet, as the abundance patterns of heavy elements which characterize sdB stars are still being documented (Edelmann et al. 2006; Fontaine et al.

2005). Thus, at this stage, it might be more appropriate to (i) determine the atmospheric parameters of hot B subdwarfs on the basis of optical spectroscopy and synthetic spectra as sophisticated as possible; (ii) calculate the ultraviolet continuum predicted at the values of $T_{\rm eff}$, log g and He/H derived in the optical; and (iii) investigate to what extent the predicted ultraviolet continuum is consistent with that observed with the FUSE satellite. We have undertaken such an exploratory study on a small sample of hot B subdwarfs and present here preliminary results from this investigation.

2. OBSERVATIONS, MODELS AND BALMER LINE FITS

Ten subdwarf B stars were selected for this analysis. The optical spectra were secured using the 2.3 m telescope at Steward Observatory, while the far-ultraviolet spectra were obtained through the FUSE satellite archives. We computed pure hydrogen and mixed helium and hydrogen (log He/H = −2.5), NLTE model atmospheres using version 200 of TLUSTY (Hubeny 1988) and the corresponding synthetic spectra using version 48 of SYNSPEC (Hubeny & Lanz 1995) with the Stark broadening tables of Lemke (1997). Our model grid extends over the following parameters: $T_{\rm eff}$ = 20 000 to 60 000 K spaced by 2000 K and log g = 5.0 to 6.5 spaced by 0.25 dex. We emphasize that our grid includes no heavy elements.

The technique used to fit the Balmer lines is standard and can be summarized as follows: the observed and theoretical Balmer line profiles (Hβ-H9) are normalized to a linear continuum set to unity. The observations are then compared to synthetic spectra and a chi-squared minimization technique is then applied until a best fit is achieved between the calculated model and the observations (see, e.g., Bergeron et al. 1992). All in all, the pure hydrogen models fit the optical spectra of our target stars quite satisfactorily.

3. THE FAR-ULTRAVIOLET CONTINUUM OF sdB STARS

As we emphasized earlier, a fit to the Lyman lines carried out in the same manner as the fit to the Balmer lines is not possible: while the optical spectra show few features besides the H I and He I lines, the FUSE observations reveal numerous lines of heavy elements that mar the ultraviolet spectrum. This prevents us from clearly determining the placement of the continuum, a crucial step in the standard fitting procedure. Thus, to verify the consistency of the parameters, we adopt the following approach. With the atmospheric parameters derived from the optical spectrum, we calculate the theoretical flux at 5458.7 Å associated with each star and, on the basis of existing Strömgren photometry, fix the solid angle. This allows us to normalize the emergent flux from our model atmospheres, and to predict the ultraviolet flux received at the Earth. For all but one star in our sample, no interstellar reddening was included, although the presence of small amounts of reddening cannot be excluded. In the case of PG 0823+466, however, reddening was required, and the color excess we determine, E_{B-V} = 0.10, is not unusual even for high-latitude PG stars. Unfortunately, there are no archival IUE observation of this object which would have provided a check on this measurement.

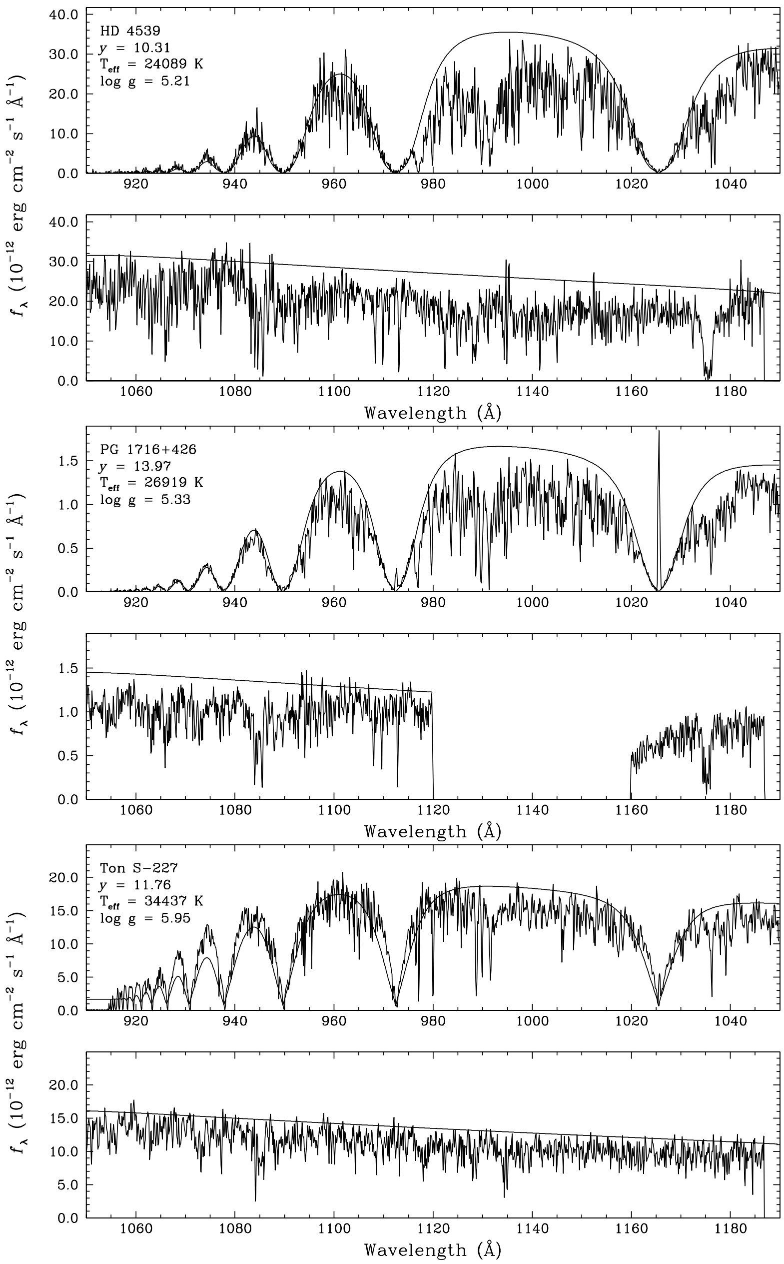

Fig. 1. Synthetic spectra calculated for three objects using the parameters derived from their optical spectrum (values are indicated in the top lefthand corner). These are superimposed onto the FUSE observations and are not fits, but rather provide a check on the consistency between the optical and ultraviolet ranges. The synthetic spectra are normalized using the y magnitude, as described in the text.

Our predictions of the ultraviolet flux are compared to the absolute flux measured by the FUSE satellite in Figure 1 for three objects in our sample. These include HD 4539, a cool and bright sdB star, PG 1716+426, the prototypical long-period sdB variable and Ton S-227, a well-studied sdB star at a somewhat higher effective temperature. The predicted fluxes are calculated on the basis of pure hydrogen or mixed hydrogen/helium models which do not include any heavy elements. For objects with $T_{\rm eff} < 30\,000$ K, our comparisons at ultraviolet wavelengths yield satisfactory results in the sense that, when some allowance is made for metal line blanketing, the synthetic spectra reproduce in a satisfactory manner the general shape of the continuum as well as the Lyman line profiles. This is shown in Figure 1 for HD 4539 and PG 1716+426. Interestingly, our procedure may provide us with a way to decide where the continuum level should be set in abundance analyses of FUSE spectra.

For objects with $T_{\rm eff} > 30\,000$ K, however, there appears to be a systematic discrepancy between the synthetic spectra derived from the optically determined parameters and the observed ultraviolet spectra. Ton S-227 provides us with a clear illustration of this situation: the predicted Lyman lines appear too wide, as if the surface gravity determined in the optical were too large, while the flux level in the interline region appears too low, in contrast to what it should be if line-blocking were the only significant omission in our models. Because some heavy elements are more abundant in hotter objects than in cooler ones, while the reverse is true for other elements, it is not possible, at this stage, to connect simply and unambiguously the trend we observe at high effective temperatures with the abundance of heavy elements. Moreover, it should be noted that Barstow et al. (2001, 2003) encountered similar discrepancies for DAs with $T_{\rm eff} > 50\,000$ K.

We are currently exploring other alternatives to account for the systematic discrepancy observed in the hotter sdB stars. Interstellar reddening, stratified H/He atmospheres, as well as homogeneous atmospheres incorporating large abundances (up to solar) of heavy elements, such as those considered by Heber (2006) and Behara & Jeffery (2006) at this conference, are currently being considered.

ACKNOWLEDGMENTS. We thank P. Chayer for useful discussions pertaining to this project. This work was supported in part by the NSERC Canada and by the Fund FQRNT (Québec)

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