Disentangling Composite Spectrum Hot Subdwarfs

M. A. Stark, Richard A. Wade (Penn State)

Abstract

We are undertaking a spectroscopic study of composite spectrum hot subdwarfs (sd+late-type). We have obtained spectra of a sample of hot subdwarfs selected from the *Catalogue of Spectroscopically Identified Hot Subdwarfs* (Kilkenny, Heber, & Drilling 1988) using near-infrared photometry from the *Two Micron All Sky Survey* (2MASS). The hot subdwarf sample consists of 20 photometric and spectroscopic single and 54 composite hot subdwarfs, 6 resolved (or barely resolved) visual doubles, and 5 objects with emission lines or broad absorption lines with emission cores. In addition the spectra of ∼100 "standard" (single late-type) stars with *Hipparcos* parallaxes were obtained for calibration. These observations cover roughly 4600–8900 Å with ∼3 Å resolution. We have measured equivalent width-like indices around Mg I b, Na I D, the Ca II infrared triplet, Hα, and Hβ. Using the single late-type star observations combined with model energy distributions, we explore how the measured indices of a composite spectrum vary as the temperature and luminosity of the late-type companion are varied and as the temperature and radius of the hot subdwarf is varied. We use the measured indices of the composite systems to estimate the temperature and gravity of the late-type star, taking into account the dilution of its spectral features by light from the hot subdwarf. The status of this effort is reported here.

I. Hot Subdwarf Sample

Hot subdwarfs were selected from the *Catalogue of Spectroscopically Identified Hot Subdwarfs* (Kilkenny et al. 1988). The observed sample consists of 20 single and 54 composite hot subdwarfs (primarily classified as sdB) that have $V \lesssim 13.5$. There are also 6 subdwarfs that have close ($<10''$) resolved companions, and 5 that show emission lines (4 of which met our composite color criterion).

Figure 1 shows the sample in 2MASS ($J-H$, $J-K_S$) color space (the solid line traces the stellar locus, hotter to the upper left; the dotted line separates the single-colored from the composite-colored subdwarfs). Composite subdwarfs for this sample were defined to have $J-K_S \gtrsim +0.05$ (Stark & Wade 2003).

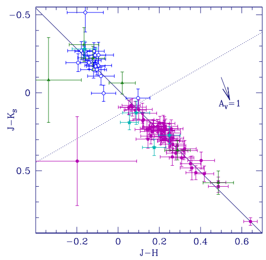

Figure 1: 2MASS Color-Color diagram for the hot subdwarf sample (○ = single; ● = composite; ▲ = subdwarf in a visual double; ⋆ = emission lines).

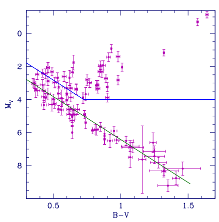

Figure 2: HR Diagram for the *Hipparcos* Standard Stars.

II. "Standard" Star Sample

Eighty-eight stars were selected with parallax measurements from *Hipparcos* to provide empirical calibration. They cover the Pop I main sequence from early F to early M-type, and post-main sequence subgiants from F to K-type ($2.7 \lesssim V \lesssim 10.0$, $-1.1 \lesssim M_V \lesssim 9.2$, and $0.35 \lesssim B-V \lesssim 1.6$). A color-magnitude diagram of the standards is shown in Figure 2 (green line indicates a least-squares fit to the main sequence, blue line indicates the cut made to divide 52 main sequence stars, below, from 32 subgiant stars, above).

III. Spectra Obtained

Spectra were taken with the GoldCam spectrograph on the Kitt Peak National Observatory 2.1m telescope. The wavelength interval ∼4600–8900 Å was covered at ∼1.3 Å/pix, using two spectrograph settings. This wavelength range includes Hα, Hβ, H-Paschen 11→limit, Mg I b, Na I D, Ca II infrared triplet (CaT), He I 5875 and 6678 Å. Unfortunate observing conditions prevented accurate flux calibration on most nights, so we consider the normalized spectra only. Example spectra covering roughly Hβ to Hα (left panel) and CaT (right panel) are shown in Figure 3, prominent lines are labelled.

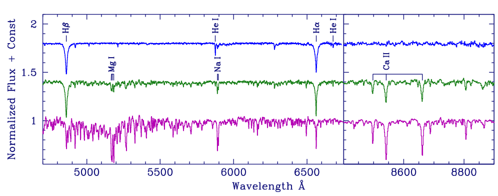

Figure 3: Example spectra for a single hot subdwarf (top), a composite hot subdwarf (middle), and a K1V standard (bottom) offset by constants. It is evident that there is less dilution at longer wavelengths.

IV. Equivalent Widths

Equivalent width (EW) indices were measured for prominent lines after fitting local continua in the regions of the lines of interest. The observed EWs for Hα (●; Hβ is similar to Hα), total Mg I b (■), total Na I D (×), and total CaT (▲) for the standard stars are shown versus M_V in Figure 4. We focus on the CaT, Na I D, and Mg I b lines.

Kurucz flux distributions were matched to the cool standards based on $B-V$ colors, with $\log g = 4.5$ used for main sequence standards and lower gravities used for the subgiants. High gravity ($\log g = 5.0$) models with $T_{\rm eff}$ = 20000, 26000, and 32000 K were used as proxies for hot subdwarfs. The observed EW for the measured lines of each of the standard stars were diluted by creating a composite with one of the three proxies, using the flux distributions to scale the contributions of the two stars appropriately. For a given hot subdwarf+cool companion combination, each of the EW indices is diluted by a different amount, according to the wavelength-dependent ratio of fluxes from the two stars, assuming radii for the hot subdwarfs from Caloi (1972, zero age horizonal branch) and main sequence radii from Gray (1992) (subgiants were scaled based on their *Hipparcos* M_V). The diluted EWs (20kK, 26kK, and 32kK hot subdwarf dilutions) are compared with observed composite hot subdwarf EWs in §V.

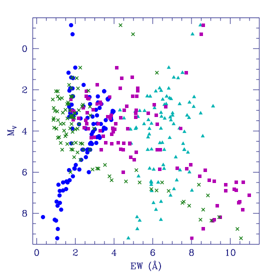

Figure 4: EW measurements for various lines from the standard stars; ● = Hα (Hβ is similar); ■ = Mg I b; × = Na I D; ▲ = total CaT.

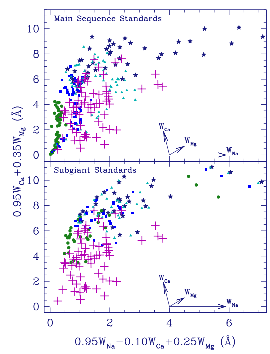

Figure 5: EWs for diluted main sequence stars (top) and subgiants (bottom) compared with observed composite hot subdwarfs (+ = observed composite sd; ★ = undiluted standards; ● = model EW, each standard diluted by a 20kK hot subdwarf; ■ = 26kK dilution; ▲ = 32kK dilution).

V. Equivalent Width Comparison

The three EWs (CaT, Na I, Mg I) form a three dimensional space. Most of the information can be shown in the 2-D subspace defined by ($[0.95W_{\rm Na} - 0.10W_{\rm Ca} + 0.25W_{\rm Mg}]$, $[0.95W_{\rm Ca} + 0.35W_{\rm Mg}]$). Using this projection, EWs for composite hot subdwarfs are plotted in Figure 5 with diluted and undiluted EWs from main sequence standards in the upper panel, and subgiant standards in the lower panel. In both panels three arrows indicate the direction and magnitude of $\Delta W = 2$ Å for CaT, Mg I, and Na I.

In both panels of Figure 5, cooler *undiluted* standard stars (star symbols) are to the right, with hotter to the left. However, in the upper panel, the cooler (fainter) *diluted* main sequence standards are at the bottom, while in the lower panel the cooler (brighter) *diluted* subgiants are to the upper right (in both cases the 20kK hot subdwarf causes the greatest amount of dilution, while the 32kK subdwarf causes the least). Both effects are due to the respective trends of M_V vs. $T_{\rm eff}$.

From Figure 5, it is seen that most composite subdwarfs can be explained by main sequence companions alone, subgiants are less successful.

VI. Diluted Color Indices

Diluted color indices were calculated using observed visual and 2MASS magnitudes for the standards, and combining them with theoretical colors for the three hot subdwarf temperatures (32kK, 26kK, 20kK) based on Girardi et al. (2002) with 2MASS color transformations taken from Carpenter (2001). The contributions from the two stars were scaled using M_V from *Hipparcos* for the standards, $L_{\rm bol}$ for the hot subdwarfs from Caloi (1972), and bolometric corrections for both standards and hot subdwarfs from Girardi et al. (2002) (standards were matched to models based on $B-V$ color). The color indices ($B-V$, $J-K_S$) are shown for the observed composite hot subdwarfs, and for each standard diluted by a 32kK (▲), a 26kK (■), and a 20kK (●) hot subdwarf in Figure 6; in this color space composite-colored stars are clearly separated from single-colored stars (see also Stark & Wade 2003).

As with the EWs (§V), the majority of composite hot subdwarfs can be explained using main sequence companions alone, while subgiants are less successful.

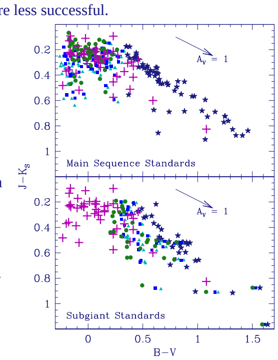

Figure 6: Color indices for diluted main sequence stars (top) and subgiants (bottom) compared with observed composite hot subdwarfs (+ = observed composite sd; ★ = undiluted standards; ● = model colors, each standard diluted by a 20kK hot subdwarf; ■ = 26kK dilution; ▲ = 32kK dilution).

VII. Individual Models

Treating the diluted EW measurements and diluted 2MASS colors indices for each standard star as a "model", the χ^2 value can be calculated between each composite subdwarf and each "model" to find a best fit. Preliminary work on this indicates that most composite hot subdwarfs favor 26kK or 32kK hot subdwarfs with **main sequence companions** in the range of $0.4 \lesssim B-V \lesssim 1$ (roughly late-F to mid-K spectral type). However, there are a few objects that favor only subgiant models, and a few that equally accept a hotter (26kK or 32kK) hot subdwarf with a main sequence companion, or a cooler (20kK) hot subdwarf with a subgiant companion. More work is needed to break these degeneracies, in particular temperature estimates (from UV spectra or Galax observations) for the hot subdwarfs would be useful. Also, we will replace the noisy observational model grid with a dense grid based on the observed behaviors.

VIII. Summary

We obtained spectra of composite colored hot subdwarfs and single cool standard stars with *Hipparcos* parallaxes. Preliminary analysis indicates that **the majority of cool companions in composite hot subdwarf systems are consistent with the main sequence**. Overall, subgiant companions do not explain the observed colors and EWs for the majority of composite hot subdwarfs. However, subgiant companions are not excluded in some cases if the hot subdwarf is relatively cool (i.e., ∼20kK). Further analysis of additional features in individual spectra and refinement of the model grids is needed to distinguish between main sequence and subgiant in these cases. An independent measure of the temperatures of the hot subdwarfs (from IUE spectra or Galex fluxes) would further constrain uncertain cases.

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