

Disentangling Composite Spectrum Hot Subdwarfs

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Abstract. We give preliminary results from a spectroscopic study of composite spectrum hot subdwarfs (sd+late-type). We obtained spectra of a sample of hot subdwarfs selected from the *Catalogue of Spectroscopically Identified Hot Subdwarfs* (Kilkenny, Heber, & Drilling 1988) on the basis of near-infrared photometry from the *Two Micron All Sky Survey* (2MASS). The 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. Spectra of 84 “standard” (single late-type) stars with *Hipparcos* parallaxes were also obtained for calibration. These observations cover 4600–8900 Å with ~ 3 Å resolution. We measured equivalent width-like indices around Mg I b, Na I D, the Ca II infrared triplet, H α , and H β . 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 are 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.

1. Samples and Observations

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 $V \lesssim 13.5$. Composite subdwarfs for this sample were defined to have $J-K_S \gtrsim +0.05$ (Stark & Wade 2003). There are also 6 subdwarfs that have close ($< 10''$) resolved companions, and 5 that show emission lines (4 met our composite color criterion).

Eighty-four stars (52 main sequence, 32 subgiant) with parallax measurements from *Hipparcos* were selected 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 $0.35 \lesssim B-V \lesssim 1.6$).

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/pixel, using two spectrograph setups. This wavelength range includes H α , H β , H-Paschen 11 \rightarrow 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 are shown in Fig. 1.

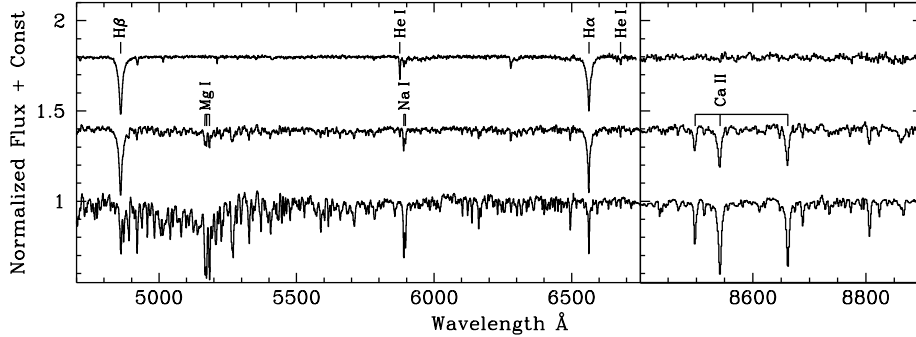


Figure 1. Example spectra for a single hot subdwarf (top), a composite hot subdwarf (middle), and a K1V standard (bottom) offset by constants. It is evident that there is less dilution at longer wavelengths.

2. Equivalent Width Measurements

Equivalent width (EW) indices were measured for prominent lines after fitting local continua in the regions of the lines of interest. 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 for the subgiants. High gravity ($\log g = 5.0$) models with $T_{\text{eff}} = 20000$, 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 horizontal branch) and main sequence radii from Gray (1992) (subgiants were scaled based on their *Hipparcos* M_V).

3. 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 $([0.95W_{\text{Na}} - 0.10W_{\text{Ca}} + 0.25W_{\text{Mg}}], [0.95W_{\text{Ca}} + 0.35W_{\text{Mg}}])$. Using this projection, EWs for composite hot subdwarfs are plotted in Fig. 2a with diluted and undiluted EWs from main sequence standards (upper panel), and subgiant standards (lower). Three arrows indicate the direction and magnitude of $\Delta W = 2 \text{ \AA}$ for CaT, Mg I, and Na I.

In both panels of Fig. 2a, cooler *undiluted* standard stars (star symbols) are to the right, 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_{eff} .

From Fig. 2a, it is seen that the EW indices can in most cases be accounted for by composite models involving main sequence companions; models with subgiants are less successful.

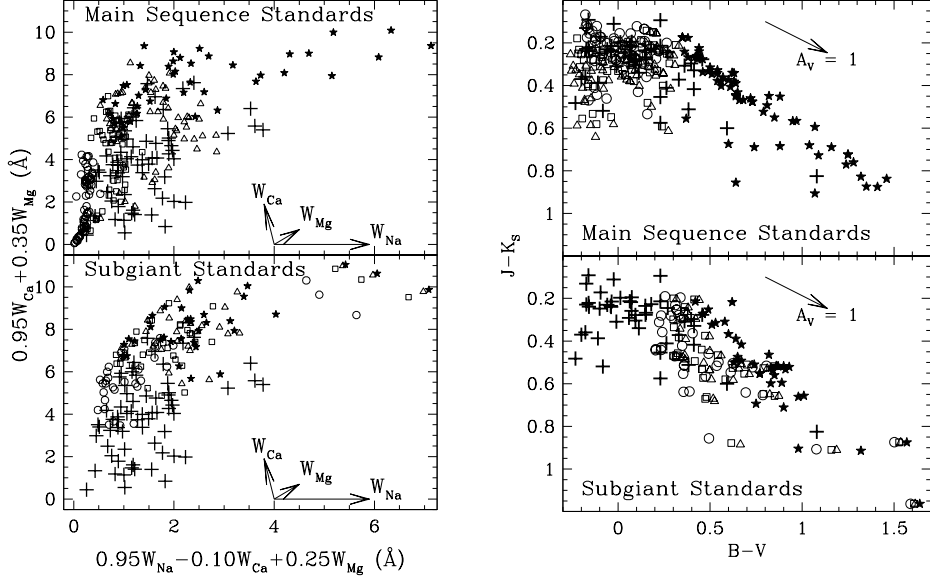


Figure 2. Panel *a* (left): EWs for diluted main sequence stars (top) and subgiants (bottom) compared with observed composite hot subdwarfs. Panel *b* (right): Color indices for diluted main sequence stars (top) and subgiants (bottom) compared with observed composite hot subdwarfs. Both panels: + = observed composite sd; star = undiluted standards; circle = model EW or colors, each standard diluted by a 20kK hot subdwarf; square = 26kK dilution; triangle = 32kK dilution.

4. 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_{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 Fig. 2b; in this color space composite-colored stars are clearly separated from single-colored stars (see also Stark & Wade 2003).

As with the EWs (§3.), the color of most composite hot subdwarfs can be explained using models involving main sequence companions, while models with subgiants are less successful.

5. 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 results indicate that most composite hot subdwarfs in our sample 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 GALEX observations) for the hot subdwarfs would be useful. Also, we will replace the sparse and noisy observational model grid with a smooth grid interpolated from the observed behaviors.

6. Summary

We obtained spectra of composite colored hot subdwarfs and single cool standard stars with *Hipparcos* parallaxes. Preliminary analysis indicates *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; but they are not excluded in some cases if the hot subdwarf is relatively cool (i.e., $\sim 20\text{kK}$). 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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