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SEARCHING FOR THE "MISSING" PG HOT SUBDWARFS IN SDSS AND GALEX DATA

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Abstract. Many EHB stars have been found in short-period binaries, where the companions in these post-common envelope systems are either white dwarfs or dM stars; these systems are catalogued as hot subdwarfs because the subdwarf is the more luminous component. Hypothesized Roche-lobe overflow systems (with more massive companions) may largely be uncatalogued, since the G band or Ca II K line from the companion may have caused them to be overlooked or discarded. In particular, many candidate objects were excluded from the PG catalog because of such spectroscopic indicators. Could these rejects include large numbers of "missing" hot subdwarfs? We have examined 2MASS, SDSS and GALEX archival data for large subsets of these rejected stars and conclude that only a handful (about 3%) show indications of binarity; most are consistent with (single) metal-poor F stars, as was originally supposed.

Key words: binaries: close – stars: horizontal-branch – ultraviolet: stars

1. HYPOTHETICAL "MISSING sdB" STARS

Binary population synthesis (BPS) models suggest that many core-helium burning, thin hydrogen envelope objects ("sdB stars") are not yet discovered, hidden in binary systems with luminous (non-degenerate) relatively cool companions. The existing catalogs of sdB stars would therefore be significantly biased, and a clear picture of the true situation regarding formation and current population of sdB stars is lacking. It is desirable to learn whether these proposed hidden populations of sdB stars actually exist.

It has been suggested (Han et al. 2002, 2003) that the stars that were rejected from the Palomar-Green (PG: Green, Schmidt & Liebert 1986, GSL86) survey for ultraviolet-excess (UVX) objects are a potential rich source for some types of these. During the PG survey, candidate UVX objects were those with (transformed) U–$B < -0.46$. Because of the large errors in U–B, $\sigma \approx 0.38$, the color selection was supplemented by classification spectroscopy, for more accurate temperature information. Many candidate UVX targets were indeed excluded from the final

PG catalog, because their spectra showed the Ca II K line (or the G band) in absorption. These rejected K-line stars were inferred to be metal-poor subdwarf F or G stars that crept into the candidate list owing to a combination of low metal-line blanketing and photometric errors.

In the alternative BPS view, these "PG-rejects" could be binaries containing sdB or sdO stars. The cool star would contribute a K line and make the blended U–B color marginal for the PG color criterion, giving a result similar to a metal-poor subdwarf. In this interpretation, therefore, the PG-rejects actually belong in the PG catalog, and moreover would constitute important evidence in favor of certain binary formation channels for sdBs.

2. THE SAMPLE OF REJECTED (K-LINE) STARS

Here we use broad-band photometry over extended wavelength ranges to assess two large subsamples from the list of PG rejects. This allows the spectral energy distribution of a composite hot+cool system to be distinguished from that of a single star. From the master catalog of 1125 PG-rejects (RW & RFG, in preparation), we found 291 stars that are present in both the Two-Micron All-Sky Survey (2MASS) Point Source Catalog and the Sloan Digital Sky Survey (SDSS) DR2 survey region, and we identified 103 stars that have GALEX observations accessible in the first Data Release. These samples are almost completely non-overlapping.

3. THE SDSS/2MASS DATASET: COLOR-COLOR DIAGRAMS

Of the 291 K-line stars that overlap 2MASS/SDSS, we consider here the 173 stars with Sloan r magnitudes in the range 14.00 to 16.00 (median $r = 14.86$) that have non-flagged (unsaturated) magnitudes in at least 4 of the 5 passbands of the SDSS (*ugriz*) photometric system (136 have all 5 optical magnitudes). All of these 173 stars have detections in the 2MASS J, H and K_s bands.

We plotted the 173 K-line stars in both g–r vs. u–g and r–K_s vs. g–r diagrams, along with 199 PG stars that have been classified as hot subdwarfs. We compared these with loci for the Population I main sequence, metal-poor main sequence and metal-poor giants (representing horizontal branch stars). We also considered three sequences of composite (binary) models. These combine the light from a hot subdwarf star ($T_{\rm eff} = 25\,000$ K, 30 000 K and 35 000 K; M_V derived from the zero-age EHB calculations of Caloi 1972) with the light from a cool main-sequence (MS) companion. These sequences emerge from the hot end of the stellar locus (faintest, coolest companions at this end), loop away from the single-star locus, and then loop back to meet the stellar locus at a (single-star) $T_{\rm eff} \approx 10\,000$ K. At this end, the 'cool' (A or F star) companion dominates.

In these diagrams, the recognized PG hot subdwarfs and the K-line PG-rejects are very different groups of stars. In this sense, the spectroscopy carried out by GSL86 succeeded in improving on the photographic U–B color selection. Some catalogued PG hot subdwarfs clearly are composite objects (Stark & Wade 2003; Reed & Stiening 2004). Most PG-reject stars, however, are consistent with being single stars, just as they were interpreted to be by GSL86. Except for a few outliers, they are not EHB+MS binary systems.

4. FITTING THE PG-REJECT STARS AS SINGLE STARS

We fitted the observed magnitudes for the 173 stars with model magnitudes, derived from the synthetic photometry done by the Padova group (Girardi et al. 2002, 2004). We considered all Padova models with $T_{\rm eff}$ in the range 4000–50 000 K, $4.0 < \log g < 5.0$ and metallicities between solar and $[{\rm M/H}] = -2.5$.

For each of the 173 stars, we scaled each model in brightness to find the best fit. We chose as the best overall model, the one that gave the smallest reduced chi-square statistic, χ^2_ν. Seven outliers have either large χ^2_ν or unusual $T_{\rm eff}$ or $\log g$. All of the remaining 166 PG-rejects can be fitted as single stars with $T_{\rm eff}$ in the range 5000–7100 K. The χ^2_ν values for these 166 non-outliers are acceptably small, given our present understanding of the SDSS error estimates, our neglect of interstellar reddening, etc. Most of these stars (136 of 166) are preferably fitted with low-metallicity models, $[{\rm M/H}] = -1.0$ or below, consistent with the GSL86 interpretation that these are metal-poor F and G subdwarfs.

Two of the outliers have SDSS spectra. They show Mg Ib, Na D and Ca II infrared triplet absorption, but the continua are blue. Both stars lie among the composite models in the color-color diagrams. A plausible model for the first is a 30 000–35 000 K hot subdwarf plus a $T_{\rm eff} \approx 6000$ K MS star. A plausible model for the second outlier is a $\sim 30\,000$ K hot subdwarf plus a $T_{\rm eff} \sim 7500$ K MS star. The other outliers lie either close to the hot single-star locus or the sequences of composite models; one may be a blue horizontal branch star.

5. THE GALEX DATASET

The GALEX photometry is in two bands, far- and near-ultraviolet (F and N), with $\lambda_{\rm eff} = 1528$ Å and 2271 Å. Figure 1 is a two-color diagram, with models of single and composite stars shown (synthetic photometry from Kurucz models). At the hot (upper left) end we show the observed colors of six known EHB stars (three of these are in binary systems, based on their 2MASS colors). We also found GALEX observations for a number of well-observed ($V \sim 9$) metal-poor single stars near $T_{\rm eff} = 6000$ K, and thus determined that the locus for such stars actually lies higher than the model line shows, by about 1–2 mag in F–N.

Of the 103 PG-rejects that were observed by GALEX, only twelve were detected in both FUV and NUV bands. We derived limits on F–N for the rest (assuming $F > F_{\rm lim} = 19.9$). We plot 24 limits in Figure 1; the other 67 systems have similar locations in the figure and are omitted to reduce confusion. Only three of the 103 stars show far-UV flux consistent with the presence of a hot star; the rest are consistent, given the errors and limits, with single cool stars. All of the "hot" detections have red J–K_s colors from 2MASS, so these stars are composite. (One of the three "hot" cases, at N–$V \approx 5.1$ and F–$N = 3.0$ is not an EHB+MS binary but can be modeled as a $T_{\rm eff} \approx 30$ kK WD+dG system.)

6. SUMMARY

A few objects ($\sim 3\%$) in our sample of PG-reject stars may plausibly be binary systems that include a hot subdwarf star as a member. The vast majority of the PG-reject stars, however, are sufficiently modeled as single stars, consistent with their being the metal-poor sdF and sdG contaminants that GSL86 were guarding against. The color-color sequences of sdB + cool (MS) star binaries are well separated from the observed colors of the PG-reject stars in both the optical vs.infrared plane and the optical vs. ultraviolet plane. There is no compelling evidence for large numbers of additional hot subdwarf stars hiding in binaries that were rejected from the PG catalog.

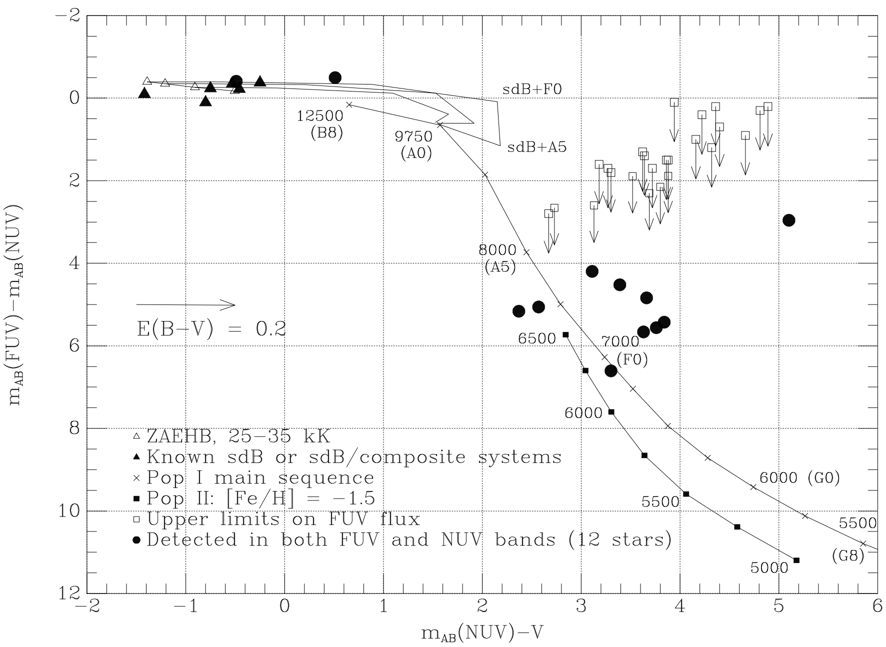

Fig. 1. GALEX and visible two-color diagram.

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