ARE ALL HOT SUBDWARF STARS IN CLOSE BINARIES?

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Abstract. We discuss whether the hypothesis that “all (or most) subdwarfs are in close binaries” is supported by the frequently reported observations of photometrically or spectroscopically composite character of many hot subdwarf stars. By way of a possible counter-argument, we focus on resolved companions (optical pairs) of hot subdwarf stars. On a statistical basis, many of these are physically associated with the hot subdwarfs, i.e. are common proper motion pairs. These resolved pairs make a several percent contribution to the catalog of hot subdwarf stars per decade in projected separation. If they are just the relatively wide members of a binary population similar to the local G-dwarf binary population (Duquennoy & Mayor, 1991), which has a very wide distribution of orbital separations, then many of the unresolved but composite hot subdwarf binaries may not be “close” in the astrophysical sense. In that case, binary channels for hot subdwarf formation may be less important than thought, or must involve companions (white dwarfs) that do not result in a composite spectrum system.

Keywords: binaries, horizontal branch stars, subdwarfs

An interesting number of spectroscopically identified hot subdwarfs (Kilkenny et al., 1988) appear to have resolved companions. It has been proposed that one or more binary mechanisms are responsible for the formation of sdB stars in particular (e.g., Mengel et al., 1976). This would imply that most or all of the sdB stars should have close companions. Are these sdBs with distant companions actually triple systems, so that they are also close binaries (Maxted et al., 2001), or instead do many field sdB stars form without binary interactions?

We restrict attention here to the 959 sdB, sd, and sdB–O stars in Kilkenny et al. (1988), from which 31 “best candidate” pairs were selected, a rate of 3.2%. The median magnitude of the 31 sdB stars is $V \sim 15$, so the typical distance is $\sim 1$ kpc, and the median angular separation of the pairs, $\rho = 10''$, corresponds to $\sim 10^4$ AU.

Using the surface density $n$ of field stars of comparable brightness, one can estimate the probability, $P(< \rho) = 1 - \exp(-\pi \rho^2 n)$, that a field star would appear within angular distance $\rho$ by chance. Selection by eye seems to have found candidate pairs which have $P(< \rho) \sim 2 - 3\%$ in the mean ($\sim 1/2$ of the candidate sample has $P(< \rho) < 1\%$). We thus expect a significant number of the sample of 31 candidate pairs to be field contamination. Nevertheless we claim that there is a significant
excess over chance (about 2–3σ) of these close but resolved pairs, i.e., some of these pairs are physical binary stars. We intend to improve upon this first selection by eye to produce a sample derived using the \( P(\rho) \) criterion directly.

Good photometric data in the visible are not available for most of the candidate pairs, either resolved or in combined light. The USNO-A2 catalog (Monet et al., 1999) gives separate entries for the subdwarf and its companion in 15 cases, with plausible photometry in “blue” (\( b \)) and “red” (\( r \)) passbands. The USNO-A2 magnitudes or colors of an individual object are dubious, but the magnitude differences and the color differences should be valid. A majority of candidate companions are brighter than the subdwarf in the “\( r \)” band. The typical candidate companion is \( \sim 1 \) mag redder (\( b-r \)) than its hot subdwarf. Six candidates (of 31) have \( P(\rho) < 2\% \) and also have USNO-A2 photometry. We assume that \( r = Johnson\ R \) and \( b-r = Johnson\ B-R \), and we adopt \( M_R = +4.5 \) and \( B-R = -0.3 \) for a typical sdB star. This allows \( r \) and \( b-r \) data for the candidate companions to be plotted in a CMD along with a main sequence locus. Although the sample size is small, the CMD is not inconsistent with the notion that the resolved companion stars to field sdB stars are largely main sequence G stars.

Better magnitude and color data are available for many of the candidate pairs from the Two-Micron All Sky Survey (2MASS). We constructed a CMD assuming \( M_J(sd) = 5.1 \) and using the observed \( J_{comp} - J_{sd} \) and \( (J-K_S)_{comp} \) from 2MASS. This diagram is not inconsistent with a main sequence nature of the companion stars. From color alone, F, G, and K stars are indicated as the dominant companion type.

Figure 1 shows a histogram of \( (J-K_S) \) for (unresolved) sdB stars (see Stark, Wade & Berriman, this volume), showing “blue” (single) and “red” (composite) cases. Tick marks and left-pointing arrows (upper limits) show the blended \( (J-K_S) \) colors of the candidate pairs, calculated from separate 2MASS measures of both components where possible. Within sampling errors and bearing in mind the contamination by field stars, the \( (J-K_S) \) distribution of the blended colors of the resolved pairs is indistinguishable from that of the unresolved “red” (composite) subdwarfs. This finding leads by another path to the conjecture that the resolved pairs and the unresolved composites are part of the same distribution: many of the candidate resolved pairs are the outer tail of a distribution of separations of physical binaries.

If the progenitors of sdB stars are solar–type stars (old disk population), we expect them to show the binary population properties of F–G dwarfs in the solar neighborhood, as summarized, e.g., by Duquennoy & Mayor, 1991 (DM91): roughly half of F–G “primaries” will have one or more companions; the distribution in \( \log P \) is broad and well–
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Figure 1. A histogram of \((J - K_s)\) for 612 (unresolved) sdB stars. Tick marks and left-pointing arrows (upper limits) show the blended colors of the candidate pairs.

approximated by a Gaussian with mean period 180 years and dispersion in \(\log P\) of 2.3 decades. For binaries with \(M_1 + M_2 = 1 M_\odot\), the mean semimajor axis is \(\bar{a} \approx 30\) AU, with a dispersion in \(\log a\) of 1.5 decades.

For a population of sdB stars with DM91–type companions at a typical distance of 1 kpc, about 6% would be resolvable with \(\rho\) in the 4–40″ range. We estimate that 1/3 to 1/2 of these would be F–G–K companions (\(|\Delta r| \leq 3\) mag). For 959 sdB primaries, we thus expect about a dozen resolved pairs, in the range of \(\rho\) and \(\Delta r\) to which the selection from Digitized Sky Survey (DSS) images was sensitive. The number of candidates found is not inconsistent with the expected number. The contamination rate is of similar size, so the size of the observed statistical excess of true binaries is not yet well established.

We must validate that the candidate pairs are true c.p.m. systems on a case–by–case basis. Data allowing this validation are at present fragmentary.

Using the DSS, the eye is only able to notice candidate pairs that have \(\rho > 3–4″\) typically. Anecdotal, but strong, circumstantial evidence exists that resolved, genuine sdB+ cool companion pairs exist at smaller \(\rho\), where field contamination is significantly less likely and a DM91 scenario predicts more binaries will be found. Reports of smaller–separated pairs include Thejll et al. (1994), Heber et al. (2002), M. A. Stark (PG 1629+081 resolved), and R. A. Saffer (GD 108 “barely resolved”). Thus it is clearly possible to search closer than the DSS...
allows and find additional resolved binaries. A survey of \( \sim 10^3 \) sdB stars in the 0.5 to 2.0" range could yield negligible field contamination (1–2 stars in 1000) and find \( \sim 5\% \) of the sdBs with companions in this range of \( \rho \), if the pairs are of the DM91 type.

A systematic review of DSS images of sdB stars has found numerous candidate sdB+companion pairs in the 4 to 40" range of separation. There seems to be a statistical excess of angularly close but resolvable systems, corresponding to true wide binaries. These resolved pairs make a several percent contribution to the catalog of hot subdwarf stars per decade in projected separation. Evidence from other studies supports the conjecture that most or many of the “composite spectrum” sdB stars are merely binaries drawn from the expected DM91–type distribution that solar–type stars should have. Further “close-in” studies, if carefully designed, can confirm or refute the DM91 conjecture.

These wide and non-interacting companions, once individually validated, may be exploited to ascertain the distance to the sdB primary. Also, the DM91 distribution, if validated, predicts that only about 1/5 of the companions noted spectroscopically or photometrically will be closer than \( \sim 2 \) AU and thus likely to interact or have interacted with the sdB star. Then the majority of cool companions that we actually identify are not participants in close binary evolution, and some mechanism not involving these companions must be invoked to provide the right amount of mass loss on the RGB and place the sdB stars where they are on the EHB. Whether that mechanism involves a single star or a multiple-star system (sdB+WD?) cannot be established from these distant cool companions.

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