# The Detection of Binary Companions to Subdwarf B Stars

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**Abstract.** We have instigated a spectroscopic survey to make unambiguous detections of cool companions to subdwarf B stars and to refine measurements of the sdB binary frequency. From an initial sample of 40 sdB stars, we have made a strong detection of the infrared triplet of singly-ionized calcium in seven cases, including Feige 87. Three of these were not previously recognized to be composite objects. These are the first spectroscopic detections of cool sdB companions. The technique is an effective means of identifying binaries and offers the potential for making direct measurements of orbits, mass ratios, and masses of sdB stars.

## 1. Introduction

The second Boulder-Munich workshop was devoted principally to studies of luminous hot stars. Whilst OB stars dominate the light from young stellar populations, hot subdwarfs dominate the ultraviolet flux from old populations such as Galactic globular clusters and giant elliptical galaxies. It is also likely that some fraction of A-type main-sequence stars (at least) become hot subdwarfs during a late stage of their evolution, probably as a consequence of interaction between the components of a binary system. It is in this context that the question of binarity amongst the hot subdwarfs is relevant to these proceedings.

The canonical picture of hot subdwarf B stars is that they are helium main-sequence stars with a mass of $\sim 0.5 M_{\odot}$ (Heber et al. 1984; Heber 1986). They possess a very thin hydrogen envelope and are burning helium in their cores. They comprise over 50% of *all* very blue objects ($U - B < -0.46$; Green et al. 1986), and are probably responsible for the ultraviolet excesses observed in giant elliptical galaxies (Brown et al. 1997).

The problem they present is an extreme form of the classical horizontal-branch problem: how can a red giant of a given mass lose a substantial fraction of its hydrogen-rich envelope (in this case nearly 100%) at or soon after the moment when helium-burning is ignited in the core?

If all sdBs were binaries, mass transfer through Roche-lobe overflow could provide a solution; however, at one time very few sdBs were known to be binaries. Conversely, the absence of binarity in sdBs would support an argument that they be formed as the consequence of a merger between two white dwarfs (Iben &

Tutukov 1986); the long (gravitational-radiation) timescale for such products is in stark conflict with their numbers. Recent advances in understanding the physical processes of stellar evolution, in particular the mixing of helium in the stellar interior, have pointed to more direct means of producing very blue horizontal-branch stars (Sweigart 1997). Whether they are created through a single evolutionary channel or through several, it is imperative to understand precisely the role and hence the incidence of binarity amongst sdBs.

Three important photometric studies of the subdwarf binary frequency, $f_{\rm b}$, all indicate values in excess of ∼50%.

- Ferguson et al. (1984) obtained spectrophotometry of Palomar-Green UV-excess targets with composite spectra and estimated $f_{\rm b} \simeq 50\%$.
- Bixler et al. (1991) examined 40 sdBs selected from UV-excess targets detected during a balloon survey. Visual and ultraviolet photometry indicated that the fluxes of 8 sdBs were composite. The authors concluded $f_{\rm b} \simeq 65$–100%.
- Allard et al. (1994) used $BVRI$ photometry of 100 sdBs and found 31 with composite flux distributions. Assuming that the companions were main-sequence stars and adopting an appropriate luminosity function, Allard et al. deduced $f_{\rm b} \simeq 54$–66%.

These estimates of the subdwarf binary frequency are subject to a number of possible errors.

- Recent measurements (Gould et al. 1996) of the luminosity function for main-sequence secondaries significantly reduce the contribution from undetected low-luminosity companions compared with previous estimates (Schmidt-Kaler 1982)
- Aperture photometry and spectrophotometry may be subject to contamination by faint line-of-sight companions.
- It is non-trivial to distinguish interstellar extinction and infrared excess.
- The assumption that the cool companions to sdB stars are low-mass main-sequence stars may not be correct.

## 2. Spectroscopic Search for sdB Binaries

The authors therefore began a spectroscopic search for genuine sdB binaries. The first objective was to detect the spectroscopic signature of cool companions. Initially, it was believed that molecular bands in the red part of the spectrum would be detected for sdBs with the coolest companions. This dictated the spectral wavelengths, resolution, and signal-to-noise ratio required.

Observations were made in 1997 February with the Isaac Newton Telescope, La Palma. Spectra were obtained in the interval 5500–9000Å at a resolution $R \simeq 2000$ and signal-to-noise ratio ∼30–100. Observations were made using a

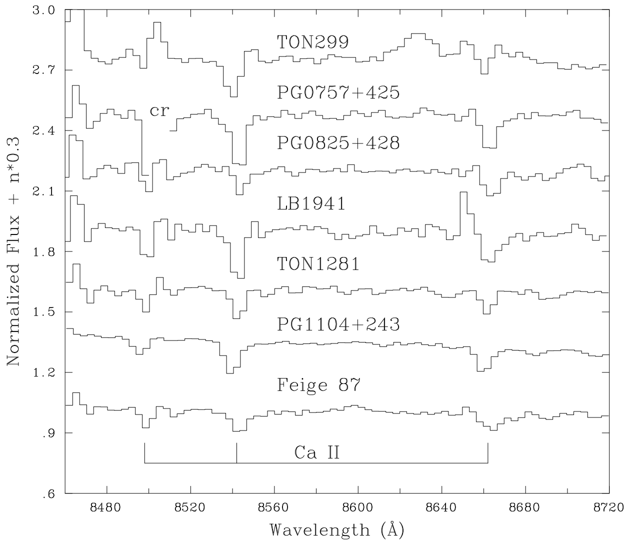


Figure 1. Spectra of seven sdB stars in the region of the Ca II infrared triplet. The spectra have been normalized and offset, but have not had any velocity corrections applied. Pixels badly affected by a cosmic ray (cr) have been removed.

narrow slit matched to the spectrograph resolution and aligned at the parallactic angle to enable relative spectrophotometry.

Forty subdwarf B stars were observed, of which 8 had previously been found to be composite and 5 had been reported as non-composite. No evidence of molecular bands was found with a detection limit of ∼1% continuum. On the other hand, the most striking result was the discovery of the infrared triplet due to singly-ionized calcium (CaT) in the spectra of seven sdB stars, including Feige 87 (Fig. 1). Of these seven stars, four had previously been reported to be composite and three were new detections. CaT was not detected in four alleged composites.

The relative fluxes at 6050, 6700, and 7050Å were combined to give nominal colour indices $f_{6700}/f_{6050}$ and $f_{7050}/f_{6700}$ (Fig. 2). These wavelengths were chosen to represent spectral windows approximately 200Å wide which were relatively free of stellar absorption, night-sky emission, and telluric absorption lines. (The night-sky and telluric lines were hard to remove from our spectra because of the modest resolution and S/N obtained, especially for the fainter stars.)

Most sdB stars have colour indices $0.63 < f_{6700}/f_{6050} < 0.70$. Moreover, the colour indices measured are mostly well correlated (Fig. 2). For sdBs in this main group, observational errors, differences in the effective temperature of the sdB stars, $T_{\rm sdB}$, and in the interstellar extinctions, $E(B-V)$, are sufficient to account for the spread in colour index.

However, a few sdBs are substantially redder than the main group, although they appear to follow an extended correlation between $f_{6700}/f_{6050}$ and $f_{7050}/f_{6700}$. Although this correlation is approximately parallel to the redden-

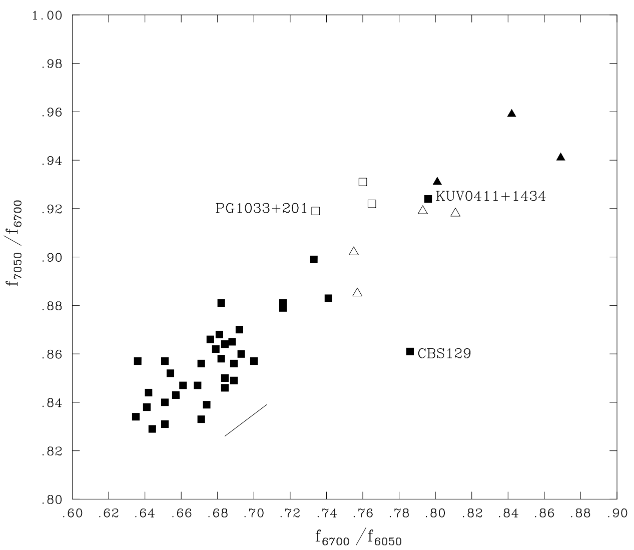


Figure 2. The two-colour diagram for subdwarf B stars, as described in the text. Triangles represent sdB stars which show the Ca II triplet (CaT); squares represent sdB stars which do not show CaT; and open symbols represent reported composite objects. Filled symbols have not previously been reported as composite. The reddening vector is shown. Labelled stars are discussed in the text.

ing line, the extinction required to account wholly for the colours of the reddest stars would be unrealistic, with $E(B-V) > 0.5$.

Chance associations with a cool near-line-of-sight companion were eliminated. For each target, a Palomar Sky Survey image $5' \times 5'$ retrieved from the Digitized Sky Survey (DSS) was inspected for possible nearby background sources. PG1049+013 was identified as a composite candidate by Allard et al. (1994). The DSS image shows a galaxy centred $9''$ from the sdB star. The galactic limb overlaps the centre of the sdB star; our spectrum shows the galactic nucleus to be active with strong emission lines. PG1049+013 shows no evidence for CaT and, in our spectra, does not show a red excess. Hence it should not be considered a composite system. PG1033+201 is also an alleged composite which does not show CaT, despite being comparatively red. The DSS image shows a 12th-magnitude star (GSC0142401026) $30''$ distant which, being 3 magnitudes brighter, may have affected aperture photometry.

Having removed contaminated targets from the sample, an excellent correlation between colour excess and the detection of CaT is revealed (Fig. 2). We find a critical value $f_{6700}/f_{6050} = 0.75$. In the present sample, five stars redder than $f_{6700}/f_{6050} > 0.77$ show CaT. Two of these were previously reported composite. Two stars with $f_{6700}/f_{6050} > 0.77$ do not show CaT. CBS129 was saturated at $\lambda < 6500$Å, and $f_{7050}/f_{6700}$ indicates the true colour to be unreddened. KUV0411+1434 shows strong Paschen lines which prevent detection of CaT and may indicate a relatively early-type companion. All sample sdBs with $0.75 < f_{6700}/f_{6050} < 0.77$ have been reported composite, and two show CaT.

## 3. Nature of the Companions

For binary stars, the entire flux distribution may be characterized, to first order, by four parameters. These are the effective temperatures of the two components $T_{\rm sdB}, T_{\rm K}$; the interstellar extinction $E(B-V)$; and the luminosity ratio $L_{\rm sdB}/L_{\rm K}$. Determination of all of these requires at least blue–visual and/or ultraviolet photometry and blue–visual spectroscopy. These are not yet available for the current sample. However, it has still been possible to deduce the general properties of the detected companions from the limited observations reported here. In a subsequent paper (Jeffery & Pollacco 1997), it is shown that if the hot stars in these systems are genuine sdB stars with luminosities appropriate for a $0.5M_{\odot}$ helium main-sequence star, then the companions responsible for the red excess and the calcium triplet must be about 5 to 20 times more luminous than a main-sequence star of appropriate effective temperature. It is not possible to solve exactly for $T_{\rm K}$, but the absence of strong TiO or $C_2$ bands in any of the current spectra requires $T_{\rm K} > 4000$ K. The use of CaT as a sensitive luminosity indicator (Jones et al. 1984) will provide further constraints on the nature of the cool companion when higher-resolution spectra become available.

## 4. Binary Frequency

In attempting to establish the nature of the cool companions responsible for the calcium triplet in the present sample, three facts have been established. All of the securely established binaries show both a red excess and the calcium triplet. If the hot stars are genuine sdB stars, then the cool companion must be a giant or subgiant. Finally, cool main-sequence companions of sdB stars could not be detected by any of the techniques adopted so far.

These facts enforce a re-evaluation of estimates of the binary frequency amongst sdB stars made by Allard et al. (1994) and others. Allard et al. assumed that the companions were main-sequence stars following a standard luminosity function and that all such companions with spectral types G8 to M had been detected. Supplementing the detection of 31 composite systems in a sample of 100 stars with a number of less luminous companions appropriate to the Schmidt-Kaler (1982) luminosity function, Allard et al. inferred a binary frequency of the order of 54%–66%.

It is generally true for all stellar populations that the number of main-sequence stars of a given spectral class exceeds the numbers of giants and sub-giants. Therefore the current conclusion that all sdB companions in the spectral range K1–M are giant or sub-giants implies that the Allard et al. measurement seriously underestimates the overall binary frequency amongst sdB stars.

Two questions remain: (i) Do the companions of sdB stars follow the same distributions in luminosity class and spectral type as single stars? (ii) Are the primaries of sdB stars with composite spectra typical of apparently 'normal' sdB stars, or are they underluminous for some reason? These questions and an evaluation of the true frequency of binarity amongst sdB stars are the subject of continuing observations.

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