A Search for White Dwarfs in the Solar Neighbourhood

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Introduction

White dwarf stars represent one of the two final stages of normal stellar evolution. Their degenerate core of a very small mass range ($0.6\ M_\odot \pm 0.2\ M_\odot$) and a radius of $< 1/100\ R_\odot$ is surrounded by a convection zone and an atmosphere with a thickness of several hundred metres. The effective temperatures for the observed objects range from 70,000 K with the colours of O stars down to 4,000 K with the colours of early M stars. This cooling sequence is due to the initial mass and the age of the stars, the coolest objects being several 10^9 years old. For further details about white dwarfs and the evolution leading to their formation see Koester (1982, *The Messenger* No. 28, p 25).

From white dwarf birth rates and cooling theory it is possible to compute number densities expected for various temperature or bolometric magnitude intervals. For hot white dwarfs ($T_{eff} > 12{,}000$ K) observations agree well with predictions (Green 1980, *Astrophysical Journal* **238,** 685), whereas theory predicts more cool white dwarfs ($T_{eff} < 8{,}000$ K) than are actually known (Liebert et al. 1979, *Ap. J.* **233,** 226). According to these authors there should be 11 white dwarfs with M_{bol} between 13^m and 15^m within a distance of 10 pc and north of $\delta = -20°$, but only 8 are known. This is not significant; however, the deficit is more pronounced for stars with $15^m < M_{bol} < 17^m$: instead of 40 only 3 are observed.

Several attempts to find these "missing" white dwarfs focused upon stars with large proper motions, but without much success. So we decided to investigate stars with small proper motions (generally less than 0.″5/year), mpg $< 15^m$, $0 > \delta > -35°$, to look for nearby white dwarfs with tangential velocities < 40 km/s. As sources for our candidates we took the Lowell Observatory GD and G Lists (Giclas, Burnham and Thomas 1980 and 1978, *Lowell Observatory Bulletin* **166** and **164**) because they provide proper motions, photographic magnitudes, colour estimates, precise coordinates and good finding charts.

Photometric Observations

From 1980 to 1983 a total of 173 stars have been observed during 6 observing periods. During the first two seasons the Bochum 61 cm telescope on La Silla was used, in 1980 with the old DC amplification photometer system and in 1981 with the new pulse-counting photometer, which now works completely computer-controlled as does the telescope mounting. This new computer control gave a better internal accuracy of the measurements (typically a few hundredths of a magnitude for stars with $V = 12^m$ to 15^m), thus significantly enhancing the efficiency of the telescope. With the Bochum telescope, observations were carried out in the UBV and Strömgren uvby systems. During the following four observing seasons we used the ESO 1 m telescope for UBVRI and uvby measurements.

Data Analysis

Classification of the stars is done by means of various two-colour diagrams. The classical diagram (Fig. 1) allows recognition of main-sequence stars with spectral types later than about B 3, of hydrogen-rich white dwarfs (DA) and of white dwarfs with helium or continuous spectra (DB or DC). The two crosses high above the black-body line represent white dwarfs with

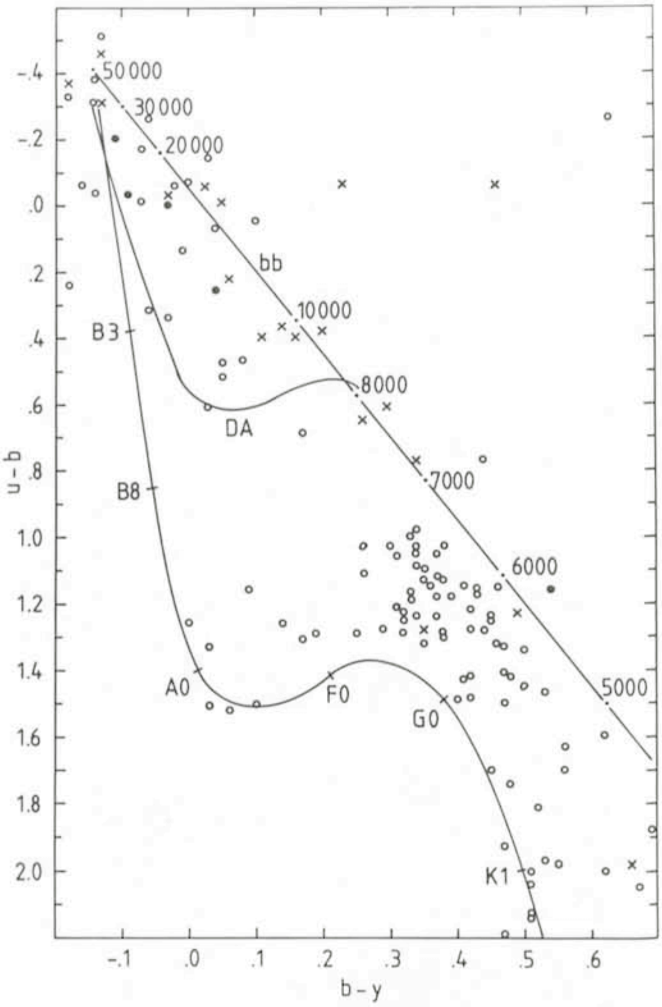

Fig. 1: *Strömgren two-colour diagram (u-b)/(b-y) of stars observed in 1980–1983 with the Bochum 61 cm and ESO 1 m telescopes on La Silla. The black-body line (bb) and the main sequence are indicated. (○) newly classified stars; (●) new observations of known white dwarf stars; (x) already known white dwarfs.*

strong C_2 absorption bands, leading initially to the suggestion that the object observed with similar colours might be a white dwarf of spectral type C_2. However, spectra taken with the ESO 1.52 m telescope (see below) show strong emission lines revealing GD 1339 as a QSO with z = 0.114. At $V_E = 14.^m6$ it is one of the brightest QSOs in the sky.

In the very hot region of the (u-b)/(b-y) diagram, however, it is not possible to separate white dwarfs with $T_{eff} > 50{,}000$ K from subdwarfs and early-type main-sequence stars. The same is true in the very cool region, where white dwarfs of $T_{eff} < 6{,}000$ K can be mixed up with subdwarfs of spectral types sdF, G and K. Both problems can be solved by introducing new two-colour diagrams where the coordinates are taken from different filter systems. Fig. 2 shows the hot end of the (u-b)/(U-V) diagram where a clear separation between the main sequence and the black-body line exists. In this diagram the white dwarfs cluster around the black-body line regardless of their spectral types. The same is true for the (R-I)/(u-b) diagram (Fig. 3).

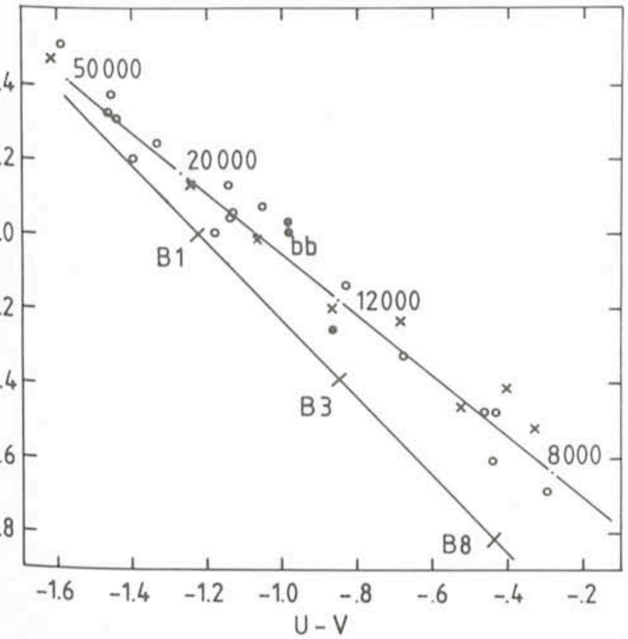

Fig. 2: *Combined two-colour diagram Strömgren (u-b)/Johnson (U-V) for hot stars. Symbols are the same as in Fig. 1.*

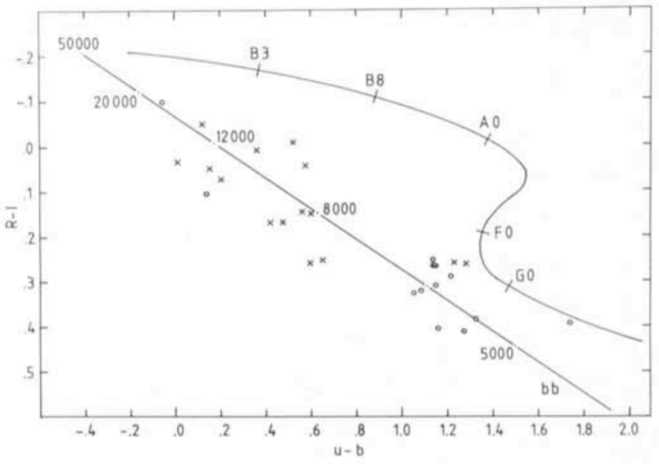

Fig. 3: *Combined two-colour diagram (R-I)/Strömgren (u-b). This diagram allows recognition of cool white dwarf stars. Symbols are the same as in Fig. 1.*

From these and similar two-colour diagrams 46 stars were classified as white dwarfs.

For achieving our goal — to determine the number of white dwarfs in the solar neighbourhood — the distances of our new objects should be known. Various colour-luminosity relations were used two derive photometric parallaxes. Absolute visual magnitudes for cool stars were derived from a M_V/(B-V) relation given by Greenstein (1976, *Astrophysical Journal* **81,** 323), from a linear regression M_V/(b-y) based on Graham's data (1972, *A. J.* **77,** 144) as cited by Green (1980, *Ap. J.* **238,** 685), and from linear regressions M_V/(u-b) and M_V/(R-I) which we calculated for stars with known trigonometric parallaxes. Since only very few hot white dwarfs have measured parallaxes, second order polynomials were fitted to hot hydrogen-rich model atmospheres (Wesemael, Auer, van Horn, Savedoff 1980, *Ap. J. Suppl.* **43,** 159) or to helium-rich (DB) white dwarfs to define again colour-luminosity relations. Distances were then computed from the calculated absolute magnitudes and the observed magnitudes. The resulting spatial distribution (excluding GD 1339) is given in Table 1).

Table 1. Distances of photometrically identified white dwarfs

Distance in parsec	cool white dwarfs	hot white dwarfs
0 – 10	12	0
10 – 20	8	3
20 – 50	1	13
> 50	0	8

Spectroscopic Observations

Although photometry is a powerful tool for the identification of white dwarfs, there still remains a chance for not recognizing some subdwarfs or binary stars. For a decisive classification, spectroscopy is necessary. Five of our photometrically identified white dwarfs have already been spectroscopically classified, mainly by Greenstein (1980, *Ap. J.* **242,** 738). During two nights in October 1982 we had the chance to take image-tube spectra of 16 others with the Boller & Chivens spectrograph at the ESO 1.52 m telescope. A dispersion of 171 Å/mm was sufficient for these stars with only a few but broad lines.

The spectra alltogether confirm the photometric classification of 14 objects; among the others are a subdwarf, a subdwarf binary and a QSO. If we apply this success ratio of $^2/_3$ to our 46 photometrically identified white dwarfs, there should remain about 30 to be confirmed by means of spectroscopy.

Results, Prospects for Future Research

The most important result of this investigation is the removal of the alleged deficit for cool white dwarfs. This is obtained by application of the just mentioned reduction factor (⅔) to our observed white dwarf numbers and extrapolation of our small observed sky area to the same total area as in Liebert et al. (1979, loc. cit.). We even find slightly more cool white dwarfs than are predicted; this stresses the need for future spectroscopic checks of the photometric identification procedure and for a better statistical basis of our success ratio.

A further result is a substantial increase of the number of observations of southern GD stars. In the sky area under consideration there are about 250 stars brighter than $m_{pg} = 15^m\!.0$. At the beginning of our project 50 stars had already been observed with 9 stars classified as white dwarfs. We add 78 stars with photometry and 14 with spectra, raising the number of white dwarfs to about 31 (after application of the reduction factor). So Greenstein's (1969, *Ap. J.* **158,** 281) initial experience has been confirmed by the present investigation: GD stars are very promising white dwarf candidates.

In addition to a large number of normal white dwarfs several objects have shown up which are of great interest individually – one extremely hot white dwarf ($T_{eff} \geq 70{,}000$ K, spectral type supposedly DO), one star with a continuous spectrum (DC), a nova-like variable just dropping from its permanent maximum, and an excitingly bright QSO. For these objects extended investigations are planned or already being carried out (e.g. observations with the IUE satellite, October 1983).

It would be worthwile to continue our programme by including objects which are one magnitude fainter to improve statistics for at least one field of the Southern Sky.

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