THE SEARCH FOR CLOSE BINARY EVOLVED STARS

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ABSTRACT: We report on a search for short-period binary systems composed of pairs of evolved stars. The search is being carried out concurrently with a program to characterize the kinematical properties of two different samples of stars. Each sample has produced one close binary candidate for which further spectroscopic observations are planned. We also recapitulate the discovery of a close detached binary system composed of two cool DA white dwarfs, and we discuss the null results of Hα observations of the suspected white dwarf/brown dwarf system G 29-38.

I. INTRODUCTION

Evolved close binary systems have long been predicted to exist as the survivors of common envelope evolution in binary systems with much larger initial separations (cf. Iben and Tutukov 1979, 1984). Driven by gravitational wave radiation, their merger has been proposed to explain the origins of Type Ia Supernovae (SN Ia), the cataclysmic variables, some hot subdwarfs, and the helium-rich R CrB giants (Webbink 1979, 1984; Tutukov and Yungelson 1979, 1987; Iben and Tutukov 1984, 1987; Paczyński 1967, 1981, 1985; Tournambé and Matteucci 1986; Webbink and Iben 1987).

Although theoretical work in this area has proceeded apace, until recently the only observational results of the search for very short-period pairs of evolved stars have been negative. Robinson and Shafter (1987) reported null results from a comprehensive spectrophotometric radial velocity search for the very close white dwarf pairs of most interest for the merger hypothesis of SN Ia formation. They found no pairs with orbital periods between 30 seconds and 3 hours among their sample of 44 white dwarfs and concluded that close binaries in this period range cannot constitute more than 1/20 of the local population of white dwarfs. The discovery by Saffer, Liebert, and Olszewski (1988) of a close double DA white dwarf system with a period of 1.56 days (further described in §IV) confirms the existence of products of common envelope evolution, but it does little to explain the apparent lack of very short-period pairs. It is important to continue the search for both short-period and longer-period pairs in order to improve understanding of the late stages of stellar evolution.

II. OBSERVATIONS AND RADIAL VELOCITY MEASUREMENTS

All observations (save one described in §V) were obtained at the Multiple Mirror Telescope (MMT) Observatory. The echelle spectrograph and photon-counting Reticon were centered at either Hα or at He II λ4686. The first sample for which these observations have been obtained comprises a subset of the hot, helium-rich subdwarf O (SdO) stars drawn from the ultraviolet-excess surveys of Green, Schmidt, and Liebert (1986) and Downes (1986). Results from a second sample composed of white dwarf/M dwarf common proper motion pairs drawn from the Luyten catalogues will be discussed separately in detail (Oswalt, Hintzen, Sion,

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and Liebert, in preparation). Multiple radial velocity measurements have been made only for the first sample. However, each sample has produced one evolved binary candidate for which spectroscopic follow-up is planned.

Figure 1 shows a) a typical spectrum of an sdO star showing absorption at He II λ4686 and b) a much higher quality spectrum showing an emission reversal in the line core. High resolution observations of sdO stars often show a sharp core in the He II λ4686 absorption line, making it possible to measure relatively precise radial velocities in spite of the Stark-broadened profiles and poor signal-to-noise ratios of most of the spectra. Radial velocities were measured by fitting modified Lorentzian profiles to the spectral features using the algorithm of Levenberg and Marquardt. Standard uncertainties were computed from the covariance matrices of the fits.

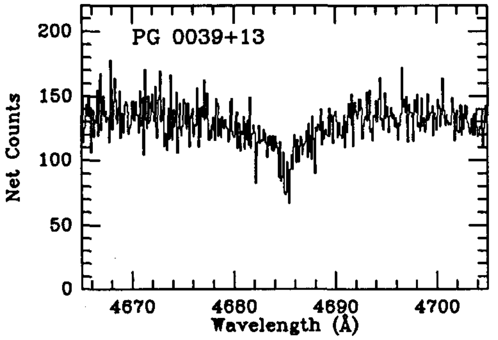

Figure 1a.

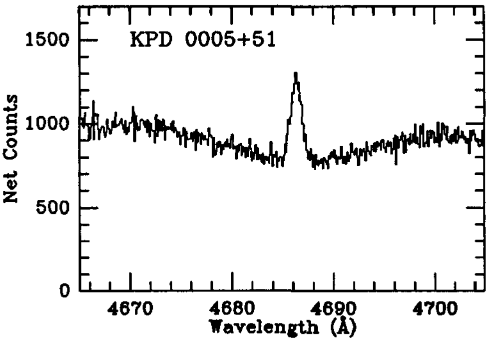

Figure 1b.

III. RESULTS FROM THE HOT SUBDWARF SAMPLE

We have measured radial velocities for 53 sdO stars drawn from the Palomar Green (PG) and Kitt Peak Downes (KPD) surveys (Green, Liebert, and Saffer, GLS, in preparation), of which 39 have two or more independent observations. Standard errors range from 10 km s^{-1} for stars with spectra having very sharp absorption cores or emission reversals to more than 100 km s^{-1} for stars with weak features or with spectra having very poor signal-to-noise ratios. Most measurements have standard errors of 30–50 km s^{-1}. Within the errors, only one star, PG 1102+499, shows radial velocity variations. Two spectra obtained in 1988 January and March show variation of the line profile shape (Figure 2). The velocity separation of the absorption cores in the March spectrum is $\Delta V = 124 \pm 42$ km s^{-1}. Further observations are scheduled to confirm the binary nature of the object and determine its orbital and stellar parameters. Of the remaining 39 objects with two or more independent observations, only 14 have weighted radial velocities which differ statistically from zero, and of these, only 3 have radial velocities exceeding ± 100 km s^{-1}. One object, PG 1047-066, has a single measured velocity of $+293.0 \pm 34.2$ km s^{-1} (Figure 3).

More observations are planned for those stars with only one radial velocity measurement. Even so, the 39 stars with 2 or more measurements constitute a statistically significant sample for characterizing the kinematic properties of the sdO stars in the solar neighborhood. The relative dearth of high-velocity stars indicates that 1) the stars in the sample are predominately young and old disk objects, and 2) the percentage of sdO stars with a close binary companion of comparable mass is small. The discovery of only one binary candidate does not strongly support the hypothesis that the blue and extended blue horizontal branch stars are the core helium-burning products of close binary evolution. However, the sample is composed of the very hottest subdwarfs ($T_{eff} \gtrsim 30{,}000$ K), and it well could include

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stars hot and/or luminous enough to be normal products of post-asymptotic giant branch evolution. A better test of the binary hypothesis of hot subdwarf formation might be made using the subdwarf B (sdB) stars, since their range of temperatures better separates them from the post-AGB tracks of single stars.

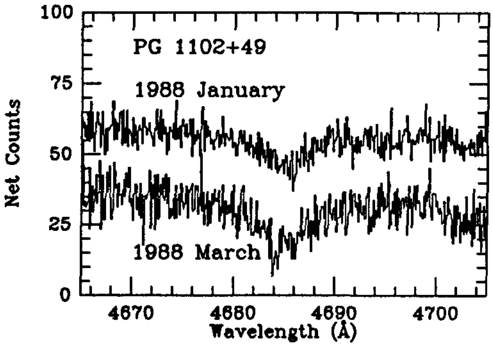

Figure 2.

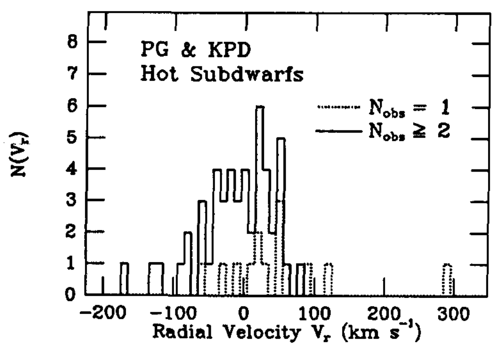

Figure 3.

IV. L 870–2: A CLOSE DOUBLE DA WHITE DWARF BINARY SYSTEM

In the 1988 November 15 issue of the Astrophysical Journal, Saffer, Liebert, and Olszewski (SLO, 1988) report the discovery that the well-studied cool white dwarf L 870–2 (EG 11, WD0135–052) is a double-lined spectroscopic binary composed of two DA white dwarfs. The orbital and stellar parameters of the system were determined from observations obtained at the MMT in 1987 September and November. Figure 4 shows representative spectra of the system at conjunction and quadrature, and Figure 5 shows the best-fit sine curves to all phased velocities measured when the two components were clearly resolved. The estimated orbital period is 1.56 days and the maximum velocity separation of the components is 147 km s^{-1}.

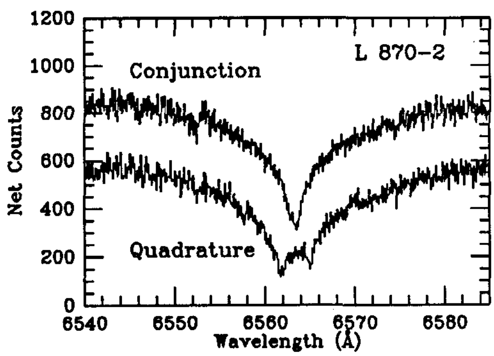

Figure 4.

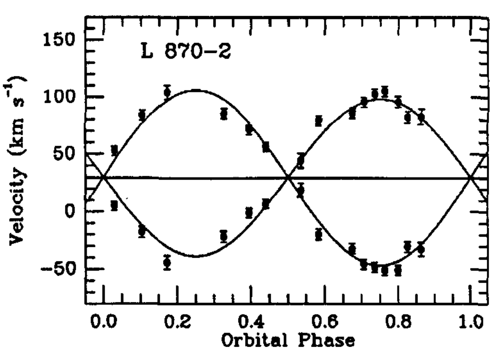

Figure 5.

Previous atmospheric and astrometric analyses indicate that the surface gravities and masses of the stars are significantly smaller than those of field white dwarfs (Koester, Schulz, and Weidemann 1979; Shipman 1979; Schulz and Wegner 1981; Greenstein 1985; Bergeron *et al.* 1988). Combined with the 1.56 day orbital period, the small masses imply that, if gravitational wave radiation is the only angular momentum loss mechanism, a merger will not occur for many Hubble times and will not produce a SN Ia. Even so, the existence of this system demonstrates that close detached pairs of degenerate stars *do* emerge from phases of common envelope evolution.

The circumstances surrounding the discovery of the binary nature of the system deserve further discussion. Greenstein (1985) showed that L 870–2 is 1.1 magnitudes overluminous in an H–R diagram plotting M_V versus the multichannel (g–r) color. In Figure 6, we show a similar diagram using the color (v–i)+(g–r) favored by Greenstein (1986) as the independent variable. In this diagram, L 870–2 lies some 1.5 magnitudes above the quadratic fit to the data. If the two components of an unresolved binary system contribute equally to the combined light, as SLO argue for L 870–2, the total luminosity should exceed that of a single star by 0.75 magnitude. The excess of 1.5 magnitudes can be explained by the smaller than average mass (and larger than average radius) of both components of the system. Another example is G 107–70, which was noted to be overluminous in the same diagram before it was discovered to be a barely-resolved binary (Strand, Dahn, and Liebert 1976). Thus, it may be possible to discover other close binary white dwarfs from spectroscopic or photometric observations of stars which appear overluminous in H–R diagrams, provided that accurate parallaxes can be measured. In fact, our own interest in the L 870-2 system in this regard has been driven strongly by its extremely accurate parallax measurement. We applaud and encourage the practitioners of this most venerable profession.

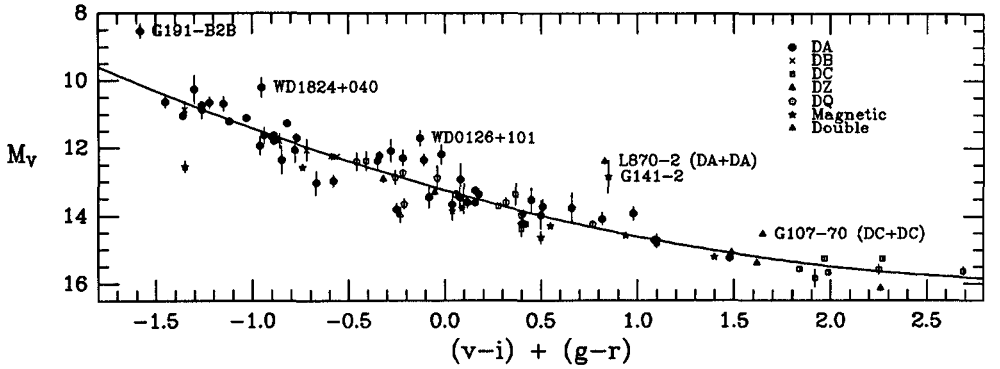

Figure 6.

V. Hα OBSERVATIONS OF THE SUSPECTED WHITE DWARF/BROWN DWARF BINARY SYSTEM G 29–38

We have obtained high dispersion spectroscopy of the Hα absorption line of the cool DA white dwarf G 29–38 (Liebert, Saffer, and Pilachowski, submitted). This is the star for which a recently detected infrared excess has been suggested to be due to a possible brown dwarf companion by Zuckerman and Becklin (1986, 1987). Echelle spectra obtained at the MMT and at the Mayall 4m telescope in 1987 December show no evidence for radial velocity variations larger than $\sim 1.1 \pm 8.7$ km s^{-1} and are used to derive a weighted heliocentric radial velocity $V_r = 33.7 \pm 4.3$ km s^{-1} for the white dwarf. Precise radial velocity measurements are possible in spite of the highly Stark-broadened Hα wings thanks to the presence of a sharp, non-LTE core. No emission component from the hypothesized secondary star is detected.

These negative results do not constitute strong evidence against the companion hypothesis, since the expected orbital velocity of the white dwarf component could be quite small (Shipman, MacDonald, and Sion, 1988), and the companion's line emission could be too faint to be detected. However, the observation of the sharp absorption core restricts the possible rotation of the white dwarf to ≤ 40 km s^{-1} and ensures that any surface magnetic field has a strength $\leq 10^5$ gauss. These results make it unlikely that the DA white dwarf has previously been spun up in a cataclysmic variable accretion phase.

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VI. SUMMARY

In the past year, we have witnessed a veritable explosion of interest in and results from the search for close binary evolved stars. The discovery by SLO that L 870–2 is binary conclusively demonstrates that close detached pairs of evolved stars can and do emerge from post-main sequence evolution in binary star systems. The discovery of a binary hot subdwarf by GLS implies that the cores of the component stars need not have evolved to the degenerate configuration, and it raises questions which recommend the re-examination of the standard theories of post-main sequence evolution, especially as they apply to the formation of the hot subdwarfs.

VII. REFERENCES

Bergeron, P., Wesemael, F., Liebert, J., Fontaine, G., and Lacombe, P. 1988, these proceedings.

Downes, R. A., 1986, *Astrophys. J. Suppl.,* **61**, 569.

Green, R. F., Schmidt, M., and Liebert, J. 1986, *Astrophys. J. Suppl.,* **61**, 305.

Greenstein, J. L. 1985, *Publ. Astron. Soc. Pac.,* **97**, 827.

Greenstein, J. L. 1986, *Astron. J.,* **92**, 867.

Iben, I. and Tutukov, A. V. 1984, *Astrophys. J. Suppl.,* **54**, 335.

Iben, I. and Tutukov, A. V. 1987, *Astrophys. J.,* **313**, 727.

Koester, D., Schulz, H. and Weidemann, V. 1979, *Astron. Astrophys.,* **76**, 262.

Paczynski, B. 1967, *Acta Astron.,* **17**, 287.

Paczynski, B. 1981, *Acta Astron.,* **31**, 1.

Paczynski, B. 1985, Cataclysmic Variables and Low Mass X-Ray Binaries, Eds. D. Q. Lamb and J. Patterson, (Dordrecht: Reidel), p. 1.

Robinson, E. L. and Shafter, A. W. 1987, *Astrophys. J.,* **322**, 296.

Saffer, R.A., Liebert, J., and Olszewski, E. 1988, *Astrophys. J.,* **334**,, in press.

Schulz, H. and Wegner, G. 1981, *Astron. Astrophys.,* **94**, 272.

Shipman, H. L. 1979, *Astrophys. J.,* **228**, 240.

Shipman, H. L., MacDonald, J., and Sion, E. M. 1988, preprint.

Strand, K. Aa., Dahn, C. C., and Liebert, J. 1976, *Bull. A. A. S.,* **213**, 468.

Tournambè, A. and Matteucci, F. 1986, *M. N. R. A. S.,* **223**, 69.

Tutukov, A. V. and Yungelson, L. R. 1979, *Acta Astron.,* **29**, 665.

Tutukov, A. V. and Yungelson, L. R. 1987, Second Conference on Faint Blue Stars, (IAU Colloquium 95), Eds. A. G. D. Philip, D. S. Hayes and J. Liebert, (Schenectady: L. Davis Press), p. 435.

Webbink, R. F. 1979, White Dwarfs and Variable Degenerate Stars, (IAU Colloquium 53), Eds. H. M. Van Horn and V. Weidemann (Rochester: University of Rochester), p. 426.

Webbink, R. F. 1984, *Astrophys. J.,* **277**, 355.

Webbink, R. F. and Iben, I. 1987, Second Conference on Faint Blue Stars, (IAU Colloquium 95), Eds. A. G. D. Philip, D. S. Hayes and J. Liebert, (Schenectady: L. Davis Press), p. 445.

Zuckerman, B. and Becklin, E. E. 1986, *Astrophys. J. (Letters),* **319**, L99.

Zuckerman, B. and Becklin, E. E. 1987, *Nature,* **330**, 138.

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