AN UNSUCCESSFUL SEARCH FOR WHITE DWARF COMPANIONS TO NEARBY MAIN SEQUENCE STARS

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ABSTRACT

Many of the nearest white dwarf stars (e.g., Sirius B and Procyon B) are in such binaries and would have remained undiscovered if they were even a little bit further away. White dwarfs which are sufficiently hot (T(eff) > 10,000 K) would, if present in binary systems with a relatively cool (F, G, K, or M) main-sequence secondary, be visible in IUE images as a hot companion to the main sequence star. We systematically examined 318 IUE images of 280 different G, K, and M stars which had been observed for other purposes. No previously undiscovered white dwarf stars were found.

Understanding the evolution of the stellar population of the Milky Way Galaxy requires that we have a reasonably good knowledge of the space density of its stellar constituents. However, cursory examination of the stars within a few parsecs indicates that there is a potential, major uncertainty in that we do not know how many white dwarf stars remain undiscovered because they are binary companions to main sequence stars and would be hidden in the same way that Sirius B and Procyon B would be even if they were at modestly greater distances. To be more specific, the four white dwarf stars within five parsecs of the sun are Sirius B (d=2.7 parsecs), Procyon B (3.5), van Maanen 2 (4.2), and 40 Eri B (4.9). The nearest two of these objects (Sirius B and Procyon B) would undoubtedly be missed by a photometric or proper-motion survey relying on wide-field images like Schmidt plates. It is these surveys which discover most white dwarfs and which are the basis for statistical arguments. Even 40 Eri B, 1 arc min from 40 Eri A, might well be overlooked in such a survey were it 50 pc away rather than 5. The potential presence of such white dwarf companions to main sequence stars was illustrated clearly when a CCD search for brown dwarf companions to nearby stars accidentally uncovered a previously unknown white dwarf

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component in a binary system (Skrutskie, Forrest, and Shure 1985).

An easy way to search for binary white dwarfs is to restrict one's attention to those which are hot enough to show a continuum in the IUE spectral region. In fact, several such companions have been discovered (Bohm-Vitense 1980, Schindler et al 1982, Stencel et al. 1984) though in a few cases the reality of the companion is in dispute (Imhoff 1985). Since we did not discover any undiscovered companions we don't need to worry about whether some of our discoveries are scattered light masquerading as an ultraviolet continuum.

Based in the IUE observing log, we selected a number of spectra of G, K, and M-type main sequence stars which were sufficiently well exposed (exposure time > 15 min) so that a white dwarf with T(eff) > 10,000 K would in fact be visible. Examination consisted of visual inspection of the photowrites. Tests indicated that visual inspection is sufficient to detect a continuum at DN = 20 or so, depending on the quality of the image.

We did not discover any new white dwarf stars. We examined 108 G stars, 118 K stars, and 54 M stars. For the G stars, we examined SWP images only since a significant continuum is present in the LWP spectral region. For the K and M stars we examined both SWP and LWP images, if they were available. A total of 318 IUE images were examined.

We did find two cases in which an ultraviolet continuum was present, but in both cases the explanations were straightforward. As it turned out, the well-known interacting binary V 471 Tauri was not delected from the list of stars to be searched before the search was undertaken. The hot white dwarf companion in this close binary system was, in fact, recognized. Another "false alarm" was Walker 92 (SWP 11044) a pre-main sequence star in the open cluster NGC 2264 investigated by Simon, Cash, and Snow (1985). We examined this star on the Palomar Sky Survey and found that the star is superposed on an H II region. We thus confirm Simon, Cash, and Snow's conculsion that the ultraviolet continuum comes from nebular emission. We analyzed a number of test cases to determine just how hot a white dwarf would have to be in order to be detectable by our search technique. We assumed that a white dwarf would have a typical radius of 0.012 solar radii, estimated the distance to the target by whatever information was available, and used unpublished models by Shipman to determine the minimum temperature of a detectable white dwarf star. Temperatures of 9,000 to 10,000 K were typical; for the remainer of this paper a white dwarf with T(eff) > 10,000 K is called a "hot" white dwarf.

The minimum temperature of white dwarfs detectable in our search is fortuitously close to the minimum temperature of white dwarfs detectable in the Palomar-Green survey for high latitude blue objects (Fleming, Liebert, and Green, 1986, hereafter FLG). As a result, the cleanest way of determining what our negative result means is to compare our results with FLG. Counting statistics

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dictate that if we found zero stars, a 3 sigma upper limit to the average number of hot white dwarf companions in a similar sized sample of G,K, and M stars is 5. Thus the space density of hot white dwarf companions to G,K, and M stars is constrained to be (a 3 sigma upper limit)

$$n_{comp} < (5/280)\ n_{GKM}\ \ 1/f_{aper} \qquad (1)$$

where n_{GKM} is the space density of G, K, and M stars of spectral types similar to those in our sample and f_{aper} is the fraction of the total number of binary companions which fall within the IUE aperture.

Evaluating the right hand side of (1) is reasonably straightforward. We adopt $n_{GKM} = 0.103$ stars pc^{-3} from Wielen's luminosity function (Philip and Upgren 1983). The evaluation of f_{aper} is a bit more indirect but under the circumstances its uncertainty is immaterial to our results. Most of the stars in our sample are reasonably bright, near 6th magnitude, and are approximately 10 pc away. The IUE large aperture at a distance of 10 pc is 10 AU x 20 AU, so we could detect all white dwarfs within 150 AU of the primary. Although we do not know the distribution of the semimajor axes of white dwarfs in binary systems, there is reason to believe that main sequence-white dwarf pairs should have separations which exceed their initial separation by a ratio M_{ms}/M_{wd} (Shipman, MacDonald, and Sion 1988), and so we are catching all white dwarf companions which initially had semimajor axes < 100 AU. Based on current statistics of binary separations (e.g., Greenstein 1986a,b), our search strategy is sensitive to the vast majority of conceivable companions, as was expected before the search was undertaken. Inspection of the figures in Greenstein's paper suggests that $0.8 < f_{aper} < 0.95$.

The numbers worked out in the previous paragraph suggest, using a conservative value of $f_{aper} = 0.8$, that a 3 sigma upper limit to the space density of hot white dwarf companions to main sequence stars is

$$n_{comp} < 2.2 \times 10^{-3} \text{ stars pc}^{-3}. \qquad (2)$$

When this project was designed, the accepted value of the space density of white dwarfs was the higher value of Green (1980), about twice the value in FLG of 0.6 stars pc^{-3} (this number allows for both DA and non-DA stars, assuming a ratio of DA/non-DA of 4:1). Because of this revision in the space density of white dwarfs, the results of our survey are less meaningful than they might be; all we can say is that the density of undiscovered white dwarfs in binaries is less than 3.5 times the density of single white dwarfs. The upper limit is inversely proportional to the number of stars examined, and a search with about 4 times the

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scope which we performed could discover or rule out the proposition that the number of undiscovered white dwarfs in binaries equals the number of single white dwarfs.

Based on a total mass density in single white dwarfs of 5.7 X 10^{-3} solar masses pc^{-3} (FLG), we can use our results to demonstrate that the total space density of white dwarf stars, including those which are binary companions of main sequence stars, is less than 3.5 times the density in single white dwarfs, or less than 0.025 solar masses pc^{-3}. While this is not a very tight upper limit, it confirms results cited by earlier authors (Liebert, Dahn, and Sion 1983) that white dwarfs cannot be sought as a possible constituent of the missing mass in the galactic disk, if the missing mass exists.

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