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A WHITE DWARF COMPANION TO THE MAIN-SEQUENCE STAR 4 o^1 ORIONIS AND THE BINARY HYPOTHESIS FOR THE ORIGIN OF PECULIAR RED GIANTS

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ABSTRACT

In the course of an investigation with the *IUE* satellite of the ultraviolet spectra of peculiar red giants, we have discovered a white dwarf companion to the MS star 4 o^1 Ori. Compared to models and *IUE* observations of other white dwarfs, we find it to be a DA3 star with $T_{\text{eff}} = 22{,}000$ K. The primary is optically variable, which is reflected in some UV variability in the LWP spectra, but three SWP images of various quality indicate the secondary is constant in light. Measurements of the Mg II and C II emission lines are consistent with single red giants of this type and thus are likely chromospheric in origin. These characteristics indicate that o^1 Ori is a simple binary with no interaction between the components. Then, assuming a luminosity for the secondary typical of field white dwarfs, we derive $M_V = -0.7 \pm 0.4$ for the primary, where the major uncertainty arises from the cosmic dispersion of white dwarf luminosities in the field. This value is somewhat larger than $M_V = -1.2$ as determined from other less direct calibrations for this star.

Upper detection limits are derived for hot ($T_{\text{eff}} > 15{,}000$ K) degenerate companions to four other bright MS stars, HR 363, RS Cnc, ST Her, and OP Her. Combined with the o^1 Ori observations, we argue that the nondetections for these stars are consistent with the statistics of field giant binaries and that either mass-transfer effects are not responsible for the incipient S-star nature of the MS stars, if their abundance peculiarities are recent, or that the MS stars must be older than 10^6 yr.

To assist other workers in identifying systems of this type, an atlas of *IUE* white dwarf SWP spectra illustrating the DA2–DA4 sequence is presented.

Subject headings: stars: binaries — stars: individual (4 o^1 Ori) — stars: S type — stars: white dwarfs — ultraviolet: spectra

I. INTRODUCTION

The MS stars are evolved red giants whose surface composition show incipient S-star characteristics of CNO and *s*-process element anomalies. They are thought to represent the initial transformation of M giants to S stars, and eventually will evolve into carbon stars. This process is suspected to be driven by dredge-up of interior material to the surface while they lie on the asymptotic giant branch (AGB), for which there is both theoretical (see Iben and Renzini 1983; Iben 1985) and observational (see Reid and Mould 1985; Wood 1985) evidence. Because of difficulties encountered in extending the dredge-up mechanism to peculiar red giant (PRG) stars not on the AGB, arguments have been made that certain PRGs may be close binary systems where mass transfer has been active. The surface abundance anomalies then would be due to interior material from the present secondary being deposited on the current primary's surface when the present secondary was a red giant itself. This scenario received some prominence by the discovery by McClure, Fletcher, and Nemec (1980) that all Ba II stars observed for radial velocity variations were in fact binaries (see McClure 1985). *IUE* observations have cast some doubt on the mass transfer explanation for these as a class, for although white dwarf companions have been found for several of the brighter Ba II stars, the white dwarf cooling times are longer than the evolution time off the main sequence for the present PRG star (Dominy and Lambert 1983), so that any mass transfer event must have taken place while the present PRG star was on the main sequence. If this were the case, we should now find at least a few main-sequence stars with Ba II characteristics. Whether such main-sequence stars exist in sufficient numbers to make this otherwise attractive scenario viable is still an open question, but there is some positive evidence (Lambert 1985).

A similar question could be asked regarding other PRG stars. Which are binaries? Some information is already available (McClure 1985; Beavers and Eitter 1987), but much more is necessary regarding the interesting MS and S stars, some of which may be cooler analogs of the Ba II stars.

In the course of studying chromospheric emission in the PRG stars, we detected a white dwarf companion to one of the brighter MS stars 4 o^1 Ori (HR 1556, HD 30959). This star is classified as S3.5/1$^-$ = MS3.5 by Keenan and Boeshaar (1980) and in most respects has abundances typical for stars of this type (Smith and Lambert 1985). One outstanding difference is the presence of Tc (Smith and Lambert 1986) which is not usually found in non-Mira MS and S stars. Like most PRGs, its luminosity has been inferred only indirectly and apparently lies between $M_V = -0.5$ and -1.4 (§ III). *UBV* photometry of o^1 Ori has been obtained by Eggen (1967, 1972), who finds the star slightly variable with a total V amplitude of 0.2 mag at $V_E = 4.75$, $B-V = 1.80$ and $U-B = 2.02$. Photometry at R

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and I and some narrow-band photometry is also available (Eggen 1967, 1972). Fragmentary published visual light curves for this low-amplitude, semiregular variable yield periods close to 120 days (Eggen 1972), or 30–40 days (Eggen 1971, 1973). The reddening is only $E(B-V) = 0.04$ (Eggen 1972). From its membership in the Wolf 630 group, Eggen estimates $M_V = -1.4$ (Eggen 1969) and $M_{bol} = -3.4$. An absolute magnitude from the Ca II K-line core is quoted as $M_V = -0.60$ (Eggen 1969). Circumstellar components of the lines of Na D and Hα have been detected, and their velocities and strengths are typical for M3 III stars (Boesgaard and Hagen 1979).

A further quick *IUE* survey was performed of other bright MS stars that either had variable radial velocities or peculiar colors suggesting that they may be binary systems. No hot companions were detected and upper limits to the ultraviolet flux from possible hot compact companions for HR 363, RS Cnc, ST Her, and OP Her have been set (Johnson and Ake 1986).

In § II, we discuss the reductions performed for the o^1 Ori *IUE* observations, and in § III compare these with field white dwarfs to derive parameters of the WD and the luminosity of the primary. Detection limits for the other MS stars are derived in § IV, and in § V we revisit the binary hypothesis for PRG stars.

II. OBSERVATIONS AND DATA ANALYSIS

Observations were obtained with the *IUE* (Boggess *et al.* 1978*a*, *b*) in low dispersion with both the SWP and LWP cameras, and at high dispersion with the LWP to examine the structure and intensity of the Mg II emission. Table 1 summarizes the pertinent information about the o^1 Ori exposures Data from the Fine Error Sensor (FES) were transformed to V magnitudes (Imhoff and Wasatonic 1986), although we suspect that the color correction for stars this red may not be accurate.

The first SWP image displayed a weak spectrum extending across the entire wavelength range which could not be attributed to grating-scattered light that is evident when observing earlier type (F-K) giant stars. This discovery spectrum is too weak to perform any analysis other than broad-band flux measurements, so longer exposures were obtained to better define the continuum distribution and to look for line absorption features. In close binary systems with a cool giant or supergiant component and a hot secondary, the UV absorption spectrum often is a combination of photospheric features of the hotter secondary component with superposed absorption from an extended envelope of material blown off the primary star in a wind. In these cases care must be taken in interpreting the nature of the hot component (e.g., Ake, Parsons, and Kondo 1985).

Data analyses were performed at the Goddard Regional Data Analysis Facility. For the low-dispersion exposures, specially written software was used to manually flag image imperfections due to radiation hits and other camera artifacts in the line-by-line extracted data. The net spectrum was derived by zero-weighting these points and decreasing the size of the effective extraction slit to reduce the noise. This reprocessing eliminated spurious features that could be misinterpreted as emission or absorption lines. Of particular importance in studying hydrogen-rich white dwarfs is correcting the Lyα absorption line for contamination by geocoronal emission. For our images, the true profile could not be fully reconstructed since the geocoronal component was overexposed, although the wings of the photospheric line somewhat extend beyond the geocoronal emission. The core, however, cannot be used. No special processing was performed on the high-dispersion LWP image outside of using a preliminary calibration (A. Cassatella 1985, private communication) to convert to absolute intensity units.

Broad-band flux measurements of the SWP spectra indicate that the secondary component is constant in light to within the accuracy of the measurements. Thus the two longer exposures were added together, weighted by their respective exposure times, for further analyses. In the long-wavelength region, however, the continuum fluxes vary from 0.27 mag at 3200 Å to 0.85 mag at 2600 Å among the LWP images. We attribute this to variation in the primary star, as observed optically by Eggen (1972), which dominates the flux in this region. In the far UV, the primary star flux is an order of magnitude smaller than that of the companion, so little variation is expected.

Figure 1 illustrates the low dispersion spectra. The SWP region is the composite of all observations. The LWP spectrum is the longest exposure of the three observations, and the continuum level seen in the other two is shown. In the long-wavelength region, the continuum begins to rise longward of 2200 Å and is clearly dominated by the photosphere of the late-type primary at the longest wavelengths. The only emission lines observable at this resolution are Mg II λ2800, C II λ2325, and perhaps Si II λ1815, which are typical chromospheric lines in stars of this type. While the LWP continuum levels change in concert with the FES visual light measures, the net integrated Mg II flux appears to be nearly constant (Table 1), with the greatest difference due to measurements at high and low dispersion. The emission-line surface flux is similar to that for other M red giants and S stars. We find no evidence for

TABLE 1

IUE OBSERVATIONS OF o^1 ORI

Date	Image Number	Dispersion	Exposure Time (minutes)	$f_{\rm Mg\,II}$ (ergs cm^{-2} s^{-1})	V_{FES}
1985 Jan 21.........	LWP 5244	Low	8	2.5×10^{-12}	4.57
	SWP 24940	Low	30		
1985 Feb 7.........	LWP 5319	High	60	3.0×10^{-12}	4.55
	LWP 5320	Low	25	(overexposed)	
	SWP 25193	Low	90		
1985 Mar 31.........	LWP 5623	Low	8	2.6×10^{-12}	4.52
	SWP 25555	Low	205		

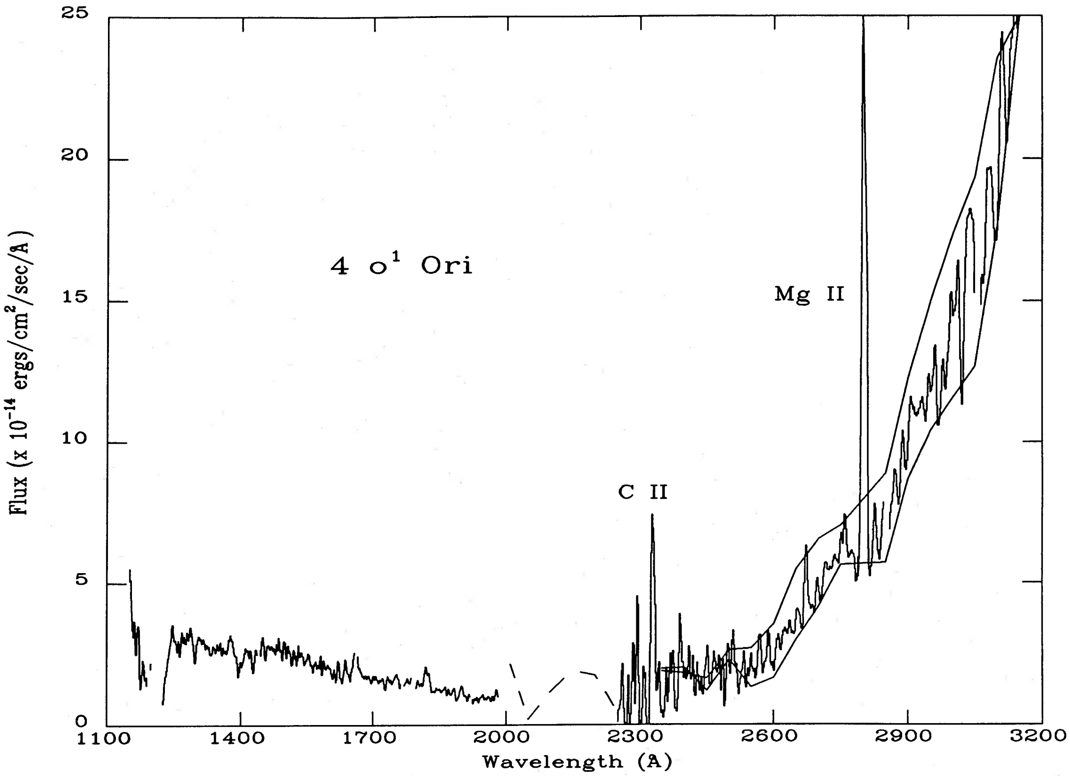

FIG. 1.—*IUE* low-dispersion spectra of o^1 Ori showing the merged SWP data and LWP 5320. For the long-wavelength region, the continuum fluxes in 50 Å bins for LWP 5244 (*lower*) and LWP 5623 (*upper*) are indicated. Since the Mg II emission in LWP 5320 was overexposed, that of LWP 5244 is shown.

emission-line outbursts either in the LWP or SWP regions as claimed by Peery (1986) and attribute the apparent variability he discussed as being due to the low signal-to-noise of his short exposures.

In high dispersion (Fig. 2), we find the Mg II profile to be typical of other late-type giant stars with no indication of added absorption due to a high-velocity wind or of effects of interaction between the hot companion and intrasystem material. The lack of significant high-temperature line emission or sharp absorption lines in the SWP spectrum supports this interpretation.

In general, the overall spectrum for o^1 Ori resembles a pure composite of two stars with no evidence of interaction between the two at this time. The emission lines are of the expected strength for the primary, and thus do not arise from intrasystem material or from an accretion disk around the secondary, such as in the S star HD 35155 (Johnson and Ake 1983). We assume then that the SWP continuum flux in particular is photospheric light from the secondary.

III. DETERMINATION OF o^1 ORI SYSTEM PARAMETERS

In Figure 3 we display the SWP spectrum dereddened by $E(B-V) = 0.04$ (Eggen 1972). In the this region, the spectrum is nearly featureless except for Lyα absorption and a broad feature near 1400 Å, both characteristic of moderately hot DA white dwarfs (Greenstein 1980; Wegner 1982). The 1400 Å feature has been shown to be a Lyα satellite line arising from the H_2 ion quasi-molecule (Nelan and Wegner 1985; Koester *et al.* 1985). The width of Lyα rules out a lower surface gravity for the secondary, such as that for a sdB star.

Using WD model by Nelan (1984), we find that a reasonable fit for the Lyα profile and the continuum is $T_{\rm eff} = 22{,}000$ K, log $g = 8$, but the 1400 Å depression would be better matched using a lower temperature or higher surface gravity model. In fact, this may be the hottest WD found so far with the 1400 Å feature. We place greater weight on fitting the Lyα profile and choose the 22,000 K value. The apparent magnitude for the o^1 Ori secondary determined from the model is $m_v = 16.5$.

Rather than depending entirely upon any particular set of WD models to further study the nature of o^1 Ori, and to search for companions to the other MS stars, we have used archival *IUE* data of field DA white dwarfs for comparison purposes. Table 2 lists the white dwarfs examined, identifies the observers, and provides references to more complete analyses on the stars. Optical data is from Greenstein (1984). The *IUE* spectra were reprocessed by us in the same manner as the o^1 Ori data. Some of the oldest SWP images were corrected for the early ITF error; some also had been processed with the old IUESIPS extraction software which samples the data at half the rate as the current software, but in stars with smooth continua and broad features such as DAs, the older extraction is sufficient.

Figure 4 displays the resultant spectra except for W1346, which lies between G87-7 and G35-29 and has been omitted for clarity. The fluxes have been converted to an energy magnitude scale where $m_v = 0$ is 3.65×10^{-9} ergs cm^{-2} s^{-1} Å^{-1}, i.e.,

$$m_\lambda = -2.5 \log (f_\lambda) - 21.09$$

and are normalized to the visual magnitudes in Table 2. The sequence illustrates the increase in Lyα width with decreasing temperature, as well as the development of the 1400 Å absorption. By converting the o^1 Ori fluxes to dereddened energy magnitudes and fitting the observations to these DA spectra, we can derive an apparent magnitude for the o^1 Ori secondary

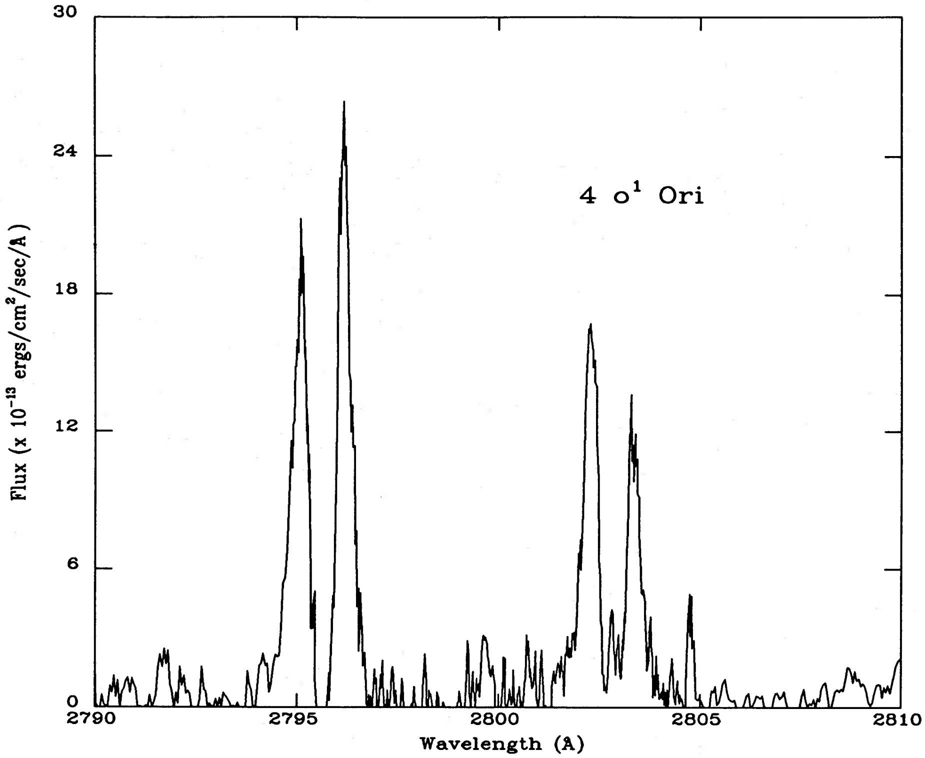

FIG. 2.—High-dispersion spectrum of the o^1 Ori Mg II lines

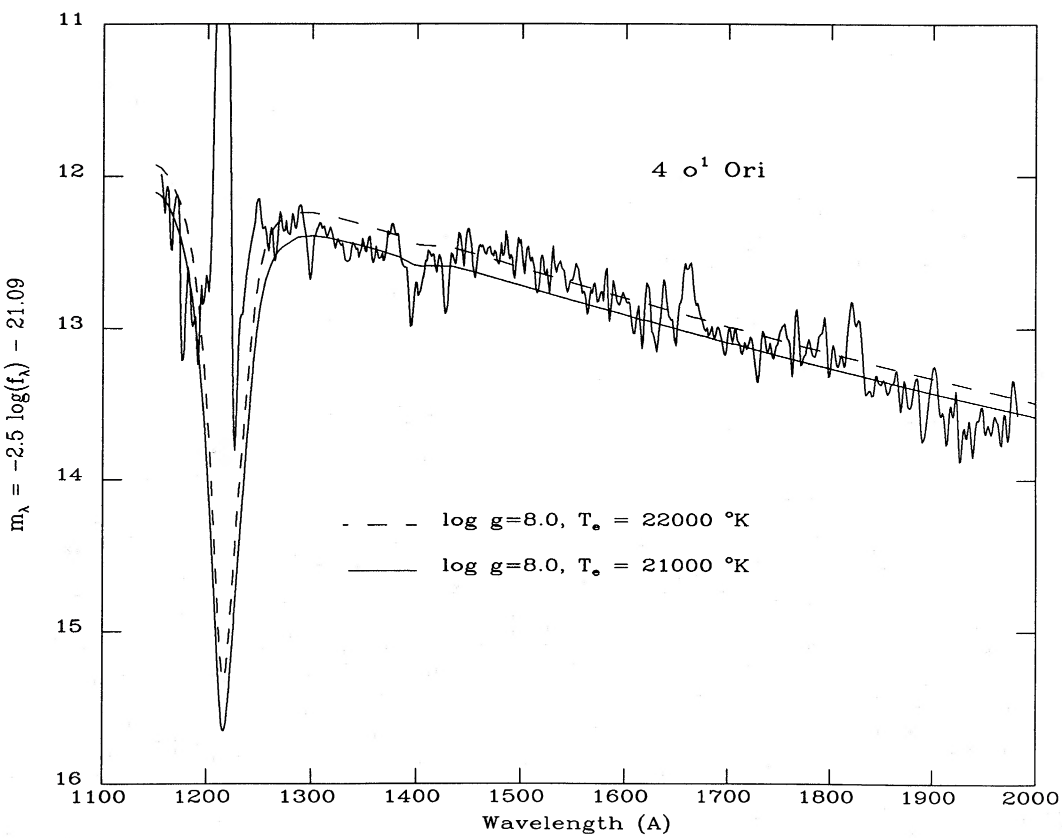

FIG. 3.—Dereddened merged SWP spectrum of o^1 Ori with model fluxes from Nelan

TABLE 2

DA White Dwarf Standards

Star ID	Spectral[a] Type	V^a, $(G-R)^a$	$M_V(\pi)^b$, $M_V(\text{color})^a$	Image Number and Observer	$\bar{f}_{1600}$ (ergs cm^{-2} s^{-1} $Å^{-1}$)	$V - m_{1600}$	T_{eff} (K)
GD 394 .... 2111+49	DA2	13.04 −.68	... 10.55	SWP 23217 Holberg	2.03×10^{-12}	4.91	33000,[c] 36125[d]
G87−7 .... 0644+37	DA2	12.00 −.67	10.82 10.59	SWP 7957 Greenstein	1.77×10^{-12}	3.72	22200,[e] 21898[f]
W1346 .... 2032+24	DA3	11.47 −.58	10.73 10.96	SWP 1650 Greenstein	2.52×10^{-12}	3.58	20680,[a] 21500,[e] 21001[f]
G35−29 .... 0205+25	DA4	13.09 −.55	10.55 11.08	SWP 15718 Koester	4.62×10^{-13}	3.35	20300,[e] 19545[f]
+73 8031 ...... 2126+73	DA3	12.68 −.53	10.80 11.16	SWP 1667 Greenstein	3.71×10^{-13}	2.70	15400,[e] 15439[f]
40 Eri B .... 0413−07	DA4	9.50 −.50	11.08 11.28	SWP 7973 Greenstein	9.46×10^{-12}	3.04	16325,[d] 16900,[e] 16942[f]
G8−8 .... 0401+25	DA4	13.91 −.41	11.75 11.62	SWP 22078 Wegner	4.82×10^{-14}	1.72	13500,[e] 13248[f]
G226−29 ...... 1647+59	DAV4	12.14 −.36	11.71 11.81	SWP 18357 Holm	1.74×10^{-13}	1.34	11800,[e] 13445[f]

[a] From Greenstein 1984.
[b] From parallaxes tabulated in Shipman 1979 and Greenstein 1976.
[c] See Koester, Liebert, and Hege 1979.
[d] See Holmberg, Wesemael, and Basile 1986.
[e] See Shipman 1979.
[f] See Koester, Schulz, and Weidemann 1979.

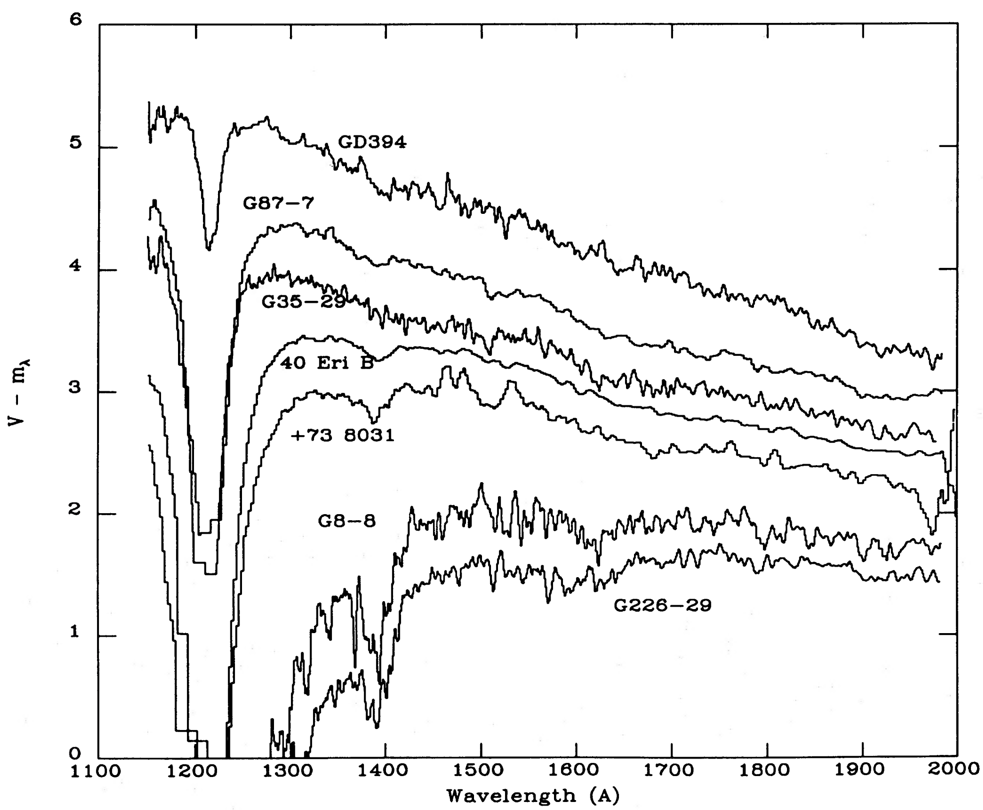

Fig. 4.—White dwarf spectra from the *IUE* archives (Table 2) on an energy magnitude scale normalized to $V = 0$ (*see text*)

from the amount of vertical shift needed to align the spectra. We find it matches W1346 and G35-29 equally well, yielding $m_v = 16.26 \pm 0.16$ mag, which is somewhat smaller than the value derived from the Nelan models. Performing the same analysis using the Nelan models to fit W1346 and G35-29, we find a zero-point correction of $m_{\rm WD} - m_{\rm Nelan} = -0.24$ for the models, which accounts for the difference. This correction arises from the use of a 22,000 K model versus temperatures of 20–21,000 K determined by other workers for W1346 and G35-29 (Table 2).

Using Greenstein's color-magnitude relation, the mean magnitude for these WDs is $M_V = 11.0$. The relation has a natural width, or cosmic dispersion, of ± 0.4 mag due to the range of masses, and hence radii, represented in the field for the DAs. With no further data on the mass of the secondary, we cannot reduce this intrinsic uncertainty. Correcting the optical data for reddening and calculating the distance modulus, we find that for the primary $M_V = -0.7$.

This luminosity is somewhat smaller than the mean determined by more indirect methods. Assigning o^1 Ori to the Wolf 630 group of old disk population stars and fitting the F and G main-sequence stars of this group to the zero-age main sequence (ZAMS) leads to a value of $M_V = -1.4$ (Eggen 1969). Absolute magnitudes inferred by this method for many stars are in agreement with those obtained from the Wilson-Bappu calibration, but there is a fair amount of scatter for the brighter stars, such as o^1 Ori (Eggen 1969). A slightly revised calibration of the Wilson-Bappu relation gives $M_V = -1.1$ for o^1 Ori, and this agrees exactly with the mean of stars for this K-line width (Wilson 1976). Since the UV Mg II lines are uncontaminated by wind or interaction effects, we can use the corresponding Weiler-Oegerle relation (1979) for our LWP exposure, where $W_{\rm Mg\,II k} = 252$ km s^{-1}, obtaining $M_V = -1.4$.

For o^1 Ori there is an uncertainty with the Ca II calibration, however, for no Ca II emission was seen by Warner (1965) on a well-exposed spectrogram whereas strong emission was later noted by Boesgaard (1969). She gave $M_V = -0.6$, based on solution II (weighted trigonometric parallaxes) of Wilson (1967). Use of solution I would yield $M_V = -0.5$. While this is somewhat fainter than the value given by solution I above according to Wilson (1976), it is consistent with two other MS stars obtained by Warner. Furthermore, the cancellation in the equation for the Wilson-Bappu effect near this magnitude renders M_V sensitive to the precise vaue of W_0 chosen.

Apparently the value of M_V from these techniques lies between -0.5 and -1.4 (Table 3), with a mean of -1.2, and the strength of the K-line emission is variable. This variability must be on the time scale of years since we found the Mg II fluxes were nearly constant over observations spread out over 3 months.

TABLE 3

o^1 Ori Parameters

Parameter	Primary Star	Secondary Star
Spectral Type	S3.5/1$^-$	DA3
m_V^a	4.53	16.26
M_V (from WD)	−0.7	11.0
M_V (from Mg II)	1.4	...
M_V (from Ca II)	−1.1	...
M_V (from group)	−1.4	...

[a] Corrected for $E(B-V) = 0.04$

IV. OBSERVATIONS OF OTHER MS STARS

For the reasons outlined in § I, it is important to search for possible compact companions to other MS and S stars as well. The bright S star HR 1105, the first for which a spectroscopic orbit has been calculated (Griffin 1984), has a white dwarf companion as well as strong C IV emission (Peery 1986). HD 35155 (Johnson and Ake 1983) appears to be an interactive system where the companion is shrouded by an accretion disk.

We have performed a quick survey of four other MS stars, as shown in Table 4. These data were taken to search for hot ($T_{\rm eff} > 15{,}000$ K) secondaries which should be seen if mass transfer has recently occurred to transform the primaries into PRGs. None were found for these, but upper detection limits for flux from possible white dwarf companions were calculated. For the MS stars, we measure the average flux in the SWP region 1250–1950 Å. These values, designated as $\bar{f}_{1600}$, are listed in column (8) of Table 4. The corresponding values for the white-dwarf standards are in Table 2, along with the $(V - m_{1600})_{\rm WD}$ color found by calculating m_{1600} as before from $\bar{f}_{1600}$. To transform the MS star fluxes to a limiting visual magnitude requires us to make an assumption about the secondary so that an appropriate $(V - m_{1600})_{\rm WD}$ color can be applied. Note that in the temperature range of stars in Table 2 (12–33,000 K), DA stars are fainter by 1–5 mag in V than in the UV.

Using a two-color $(G-R)_{\rm WD}$, $(V - m_{1600})_{\rm WD}$ relation, we are able, after correcting for reddening of $E(V - m_{1600})/E(B-V) = -5.1$, to evaluate

$$M_V\,({\rm lim}) = m_{1600} + (V - m_{1600})_{\rm WD} - (m - M)$$

for a range of $(G\text{-}R)_{\rm WD}$ colors for each MS star. These values of M_V(lim), representing the detectable light of any companion, can be used to trace a detection line in Greenstein's M_V, $(G\text{-}R)$ diagram for white-dwarf stars (Fig. 5). The upper limiting mag-

TABLE 4

Observed MS Stars

Star (1)	Spectral Type (2)	V^a (3)	$m - M^a$ (4)	$E(B-V)^a$ (5)	SWP Number (6)	Exposure Time (minutes) (7)	$\bar{f}_{1600}$ (ergs cm^{-2} s^{-1} Å^{-1}) (8)	M_V(WD) (9)
HR 363	S3$^+$/2$^-$	6.43	7.50	0.05	25192	20	2.39×10^{-15}	>11.1
o^1 Ori	S3.5/1$^-$	4.65	5.95	0.04	(merged)	...	2.03×10^{-14}	11.0
RS Cnc	M6S	5.2	7.00	0.02	25528	40	3.46×10^{-15}	>11.1
ST Her	M6.5S	7.0	~8.1	...	22834	30	2.93×10^{-16}	>11.5
OP Her	M5S	6.05	7.00	0.05	22657	28	9.28×10^{-15}	>10.5

[a] Values from Eggen 1972, except for ST Her.

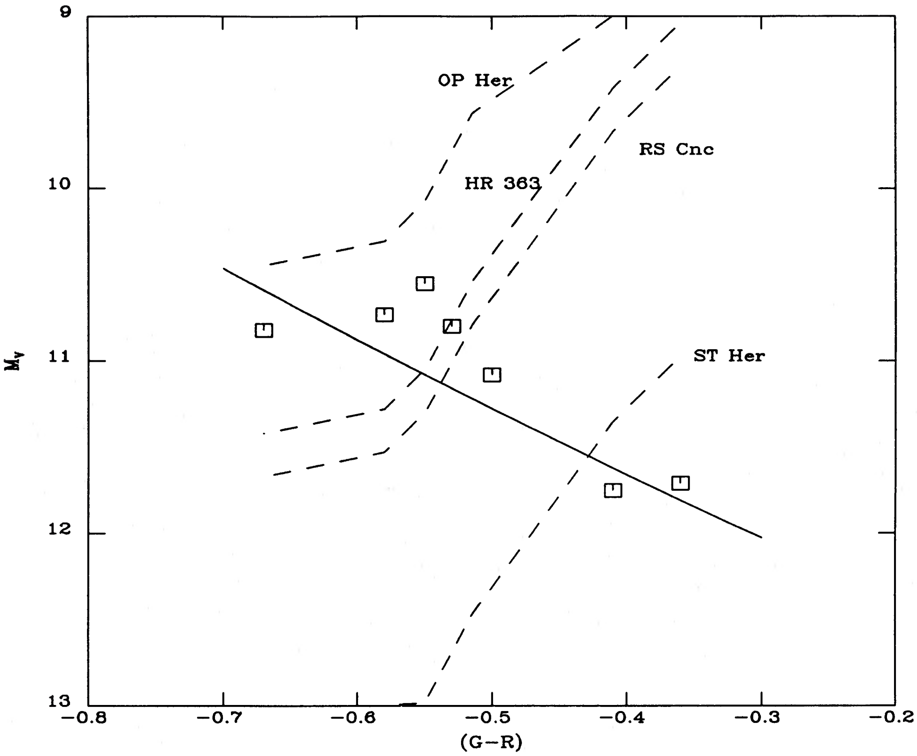

FIG. 5.—Loci of detection limits for white-dwarf companions for stars of Table 4 (*dashed lines*). The mean color-magnitude relation for DA stars from Greenstein (1984) is shown, as are parallax white dwarfs in Table 2 (*open squares*).

nitude is taken to be where this locus crosses the mean line for the degenerates. Table 4 summarizes the results.

Our observed statistics (one white dwarf companion of five MS stars) for detecting WD companions to the MS stars is no different than that for the normal field giants, which argues against the close binary hypothesis as explaining the abundance peculiarities in S-type stars. It is clear that a much larger sample of MS and S stars must be observed, and longer exposures must be taken to drive down these possible upper limits. Nevertheless, although individual cases such as HR 1105 and HD 35155 are certainly fascinating, our results so far do not support a close binary hypothesis for these stars.

V. DISCUSSION AND CONCLUSION

By definition, MS stars are those M giant stars which show enhancements of *s*-process elements. In general, however, these stars were selected on the basis of classification spectra, and careful abundance analyses are necessary to determine whether an enhancement of *s*-process elements actually exists and whether, in addition, carbon is enhanced. Such studies have now been carried out for 15 M giants, four MS stars (including o^1 Ori), and three S stars based on a comparison of synthetic spectra from model atmospheres with high-resolution observations (Smith and Lambert 1985, 1986). Abundances of C, N, and O in o^1 Ori are the same as that of both the comparison star α Tau and of six standard M giant stars—a slight deficiency of carbon and an enhancement of nitrogen, showing a past history of gentle mixing with CN processed material. A large overabundance (factor of 2) of the intermediate *s*-process elements Sr, Y, Zr, and a smaller overabundance (factor of 5) of the heavier *s*-process elements Ba and Nd appear (Smith and Lambert 1985). Perhaps more interesting is the confirmation of an earlier indication (Little-Marenin and Little 1979) of the presence of Tc in the atmosphere of o^1 Ori (G. Wallerstein 1985 private communication; Smith and Lambert 1986). This discovery is a bit surprising, for o^1 Ori does not share the characteristics of low temperature and long-period variability of the other stars which show Tc (Little-Marenin and Little 1979). This star is clearly something of an anomaly in showing Tc lines.

The ratio of (Ti/Zr) in o^1 Ori is typical for an MS star (Boesgaard 1970) and falls between the value for M stars and that of S stars. In agreement with results in other M and MS stars, o^1 Ori shows terrestrial ratios of the Ti isotopes (Clegg, Lambert, and Bell 1979). Relative to the Sun, o^1 Ori displays a ratio of (Li/Ca) which is low by about one order of magnitude, similar to other M giants of the same population (Merchant 1967).

What has been the evolutionary history of o^1 Ori and the MS stars? Perhaps there is a range of histories. The carbon and *s*-process peculiarities have been shown to be consistent with their having undergone a few dredge-up events, but single dredge-up scenarios of differing intensity, resulting in the various levels of abundance peculiarity, cannot be completely ruled out. In binary systems such as o^1 Ori, there is the added uncertainty as to whether the surface composition of the primary has been modified in the past by accreted material when what is now the secondary star was a mass-losing red giant itself.

It should be made clear that there is nothing in the chemical composition or luminosity which demands an explanation outside the usual dredge-up scenario. Nevertheless, the presence of a white dwarf companion around a star which is unusual in being both warmer and less variable than other MS stars invites a closer look. Nevertheless, all evidence indicates nothing more than the existence of a coincidence.

Since the half-life of ^{99}Tc, the longest lived isotope of Tc, is $\sim 2 \times 10^5$ years, the presence of Tc on the surface now indicates that less than 10^6 yr (i.e., a few half-lives) have elapsed since the last episode of Tc deposition on the surface. Now the cooling time of a white dwarf of $T_{\rm eff} = 22{,}000$ K is 10^8 yr (e.g., Iben and Tutukov 1984), and there is no possibility of forcing agreement in these figures. That is, there is no possibility that the Tc now present on the PRG star was deposited by the white dwarf in its previous red giant stage. Furthermore the lack of any evidence of current interaction between the two makes it appear unlikely that the components of the binary are close. Altogether then we conclude that the presence of Tc—and by implication all the *s*-process enhancements which confer o^1 Ori its distinctive status as an MS star—are unrelated to the presence of the white dwarf.

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