THE ASTROPHYSICAL JOURNAL, 200:88–94, 1975 August 15

THE ABSOLUTE MAGNITUDES OF CARBON STARS: CARBON STARS IN BINARY SYSTEMS

B. INGEMAR OLSON* AND HARVEY B. RICHER*
Department of Geophysics and Astronomy, University of British Columbia
Received 1974 September 26; revised 1975 February 10

ABSTRACT

Absolute visual magnitudes have been determined for carbon stars belonging to binary systems. These range from about 0 to brighter than -4, with a mean value of -2.3 for N stars. Bolometric corrections are deduced, giving bolometric absolute magnitudes in the range -4 to -8.

Subject headings: carbon stars — luminosities — visual double or multiple stars

I. INTRODUCTION

The position of carbon stars in the evolutionary sequence is not well understood. It is not clear, for example, whether most stars become carbon stars or if only some do, whether the carbon star phenomenon is recurrent or occurs only once, or how the core products of nucleosynthesis are transported to the surface. Moreover, carbon stars are not a homogeneous group; some are found in globular clusters while others (N stars) are strongly concentrated toward the galactic plane. The problem is compounded by the fact that many of the basic observational data are imprecise, making comparison with theoretical studies difficult. In particular, carbon star temperatures and luminosities are not accurately determined. We shall here address ourselves to the absolute magnitude problem.

Most previous studies of this question have employed statistical methods to derive mean absolute magnitudes for large groups of stars (e.g., Sanford 1944; Vandervort 1958; Richer 1971), yielding $M_V \approx -0.4$ for the R stars and -2.5 for the N stars. Baumert (1972, 1974) has derived near-infrared 1.04-μ absolute magnitudes of -4.3 ± 0.7 for the N stars. A comparison of his data with those of Sanford (1944), Mendoza and Johnson (1965), and Richer (1971) yields a color index $\langle V - I(104)\rangle = 3.9 \pm 0.7$ (σ) resulting in $M_V = -0.4$ for N stars, significantly fainter than other studies. Because of the diversity of the carbon stars, however, this approach tends to obscure the range of luminosities that actually exists. The only way to reveal this range is to determine the absolute magnitude of as many individual carbon stars as possible. Attempting to do this, Gordon (1968) considered some carbon stars in the line of sight to clusters. At present the best cases for cluster membership can be made for the carbon stars near the open clusters NGC 2477 (Catchpole and Feast 1973), NGC 2660 (Hartwick and Hesser 1973), and NGC 7789 (Gaustad and Conti 1971), and the globular cluster ω Centauri (Harding 1962; Dickens 1972) plus those in the Small Magellanic Cloud (Feast and Lloyd Evans 1973). Excepting the two CH stars in ω Centauri, the remaining (probably N type) stars have a mean absolute visual magnitude of -2.3 with a range of 2.3 mag. Westerlund (1964) found several hundred carbon stars in the Large Magellanic Cloud, giving a mean absolute magnitude of -3 and a spread of about half a magnitude.

Gordon also considered some double stars with one member a carbon star, as did Richer (1972), who found three carbon stars with composite spectra. This approach to the absolute magnitude problem has here been applied to a few dozen suspected carbon star doubles, yielding several new probable binary systems as well as better data on many of the previously studied candidates. Radial velocities have been used as the primary criterion for the physical proximity of the suspected doubles, while the luminosities of the companions have been obtained from MK spectral classifications along with Hβ indices for B type companions.

* Visiting Astronomer, Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory, which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

II. THE OBSERVATIONAL DATA

A list of carbon stars suspected of being in binary systems is given in Table 1. These have been gathered primarily from Crull (1972) and Gordon (1968), while several were found at the telescope during previous observing sessions. Column (2) gives the carbon star's R–N spectral type (Sanford 1944), the Keenan-Morgan C type as defined by Yamashita (1972), and Richer's (1971) infrared C type, while column (3) gives the companion's name, angular separation in arc seconds, and position angle with respect to the carbon star for those cases where some confusion might occur.

UBV photometry of the carbon stars and their companions has been obtained during the periods 1971 September 24–26 (Cerro Tololo) and 1972 September 10–13 (Kitt Peak), while *VRI* photometry of some of the carbon stars is available for 1971 October 12–14 and 1974 June 5–7 (Cerro Tololo).

1975ApJ...200..880

TABLE 1

OBSERVED CARBON STARS WITH COMPANIONS

Name, HD, DM	R–N, KM, Rh	Companion, Sep./P.A.
U Cam, 22611, +62 596..........	N, C5,4, ...	+62 594, 208/349
..., 34467, +35 1046............	N, C6,3, C4	..., 24/44
UV Aur, 34842, +32 957..........	Ne, C8,1Je, C9	ADS 3934 B, 3/
TU Tau, 38218, +24 943..........	N, C5,4, C5	..., 0/
MSB 22, ..., −26 2983...........	N, C4,4, C6	..., 0/
RY Mon, ..., −7 1742...........	N, C5,5, C6	..., 28/
W CMa, 54361, −11 1805.........	N, C6,3, C5	−11 1801, 158/85
MSB 31, ...	R8 ...	..., 4/
..., 75021, −29 6735............	R8, ..., ...	HD 75022, 100/180
V Hya, −20 3283................	N, ...	..., 46/186
SZ Sgr, 161208, −18 4634.........	N, C7,3, C5	..., 2/
T Dra, +58 1772a................	Ne, ...	UY Dra, 15/225
MSB 64, ..., +5 3950............	N, ..., C6	..., 28/
UV Aql, 176200, +14 3729........	N, ..., C6	..., 20/
X Sge, 190606, +20 4417.........	N, ..., C6	..., 6/
SV Cyg, 191738, +47 3031........	N3, C7,4	+47 3032, 145/140
RS Cyg, 192443, +38 3957........	Ne, C8,2e, C5	+38 3956, 132/355; +38 3960, 56/106
U Cyg, 193680, +47 3077.........	Ne, C8,2, C em	+47 3078, 64/51
MSB 41, ..., +32 3954...........	N, ..., ...	cp. 1, 10/205; cp. 2, 18/110..........
..., 209596......................	N, ...	..., 9/
RZ Peg, 209890, +32 4335........	Ne, C9,le, C em	..., 15/
MSB 73, ..., +48 3827...........	N, ..., ...	..., 6/
SU And, 225217, +42 4827........	N, C6,4, C5	..., 15/

TABLE 2

THE PHOTOMETRIC DATA

STAR	CARBON STAR V / $B-V$ / $U-B$	CARBON STAR V / $V-R$ / $V-I$	COMPANION V / $B-V$ / $U-B$	COMPANION Hβ / $E(B-V)$
UV Aur*.....	9.59	10.01	10.96	2.679
	1.42	2.43	0.21	0.20
	−0.26	4.26	−0.30	
−26 2983*....	8.56	8.72	(12.8)	...
	3.26	2.15	...	0.0
	1.35	3.56	...	...
Sz Sgr*.......	8.44	8.74	(11.8)	...
	2.31	1.99	...	0.21
	1.72	3.45	...	
TU Tau*......	8.29	...	(11.7)	...
	2.72	...	...	0.44
	1.36	...	...	...
W CMa.......	6.55	6.62	8.76	2.642
	2.38	1.76	0.00	0.24
	4.24	3.11	−0.69	...
SU And......	8.19	...	12.77	...
	2.45	...	0.38	0.07
	4.85	...	0.01	...
SV Cyg.......	8.55	...	9.75	...
	3.19	...	1.21	0.11
	5.2:	...	1.24	...
MSB 64.......	9.60	9.40	11.81	2.818
	3.79	2.41	0.73	0.58
	...	4.05	0.49	...
HD 75021.....	7.08	7.26	7.58	...
	1.94	1.51	1.45	0.35
	3.17	2.88	1.60	...
RY Mon......	7.91	8.26	12.29	...
	4.03	2.47	0.49	0.11
	...	4.06	0.01	...
RZ Peg.......	9.25	8.42	12.31	...
	3.93	1.92	0.57	0.0
	2.66	3.34	0.13	...
UV Aql.......	8.39	9.05	12.05	...
	3.55	2.46	1.53	0.88
	...	3.93	1.50	
HD 34467.....	9.20	...	12.90	2.826
	2.78	...	0.53	...
	4.28	...	0.30	...

STAR	CARBON STAR V / $B-V$ / $U-B$	CARBON STAR V / $V-R$ / $V-I$	COMPANION V / $B-V$ / $U-B$	COMPANION Hβ / $E(B-V)$
MSB 41......	9.61	...	10.72	...
	4.14	...	0.89	0.0
	...	...	0.44	...
cp. 2.........			11.94	...
			1.08	0.0
			0.80	...
X Sge.........	8.53	8.53	13.18	...
	3.35	2.14	0.77	0.41
	...	3.53	0.16	...
HD 209596....	10.18	...	12.96	2.608
	2.40	...	0.85	...
	4.05	...	0.39	...
MSB 73.......	10.29	...	12.74	2.615
	2.30	...	0.74	0.29
	3.44:	...	0.08	...
V Hya........	...	8.36	11.58†	...
	...	3.03	...	...
	...	4.69	...	...
T Dra........	12.48	...	10.99	...
	5.6:	...	1.16	...
	...	...	1.15	...
U Cam.......	7.55	...	9.63	2.816
	4.29	...	0.21	0.30
	4.49	...	−0.05	...
U Cyg........	10.08	...	7.87	...
	5.18	...	0.80	0.0
	...	...	0.51	...
RS Cyg.......	8.32	...	7.09	2.561
	3.45	...	0.50	0.75
	3.61	...	−0.45	...
cp. 2.........	...	...	9.24	...
			1.93	0.31
			2.24	...
MSB 31†......	9.0	...	10.8	...
			0.2	...

* Carbon star photometry includes companion. † See text.

$H\beta$ photometry of some of the companions was also obtained in 1972. The photometric reduction procedure was along standard lines, except that the extreme redness of the carbon stars made it necessary to account for the red leak in the U filter. Transformation to the Arizona-Tonantzintla system (Iriarte *et al.* 1965) resulted in mean residuals of 0.02 mag for V, $B - V$, and $U - B$ and 0.03 for $V - R$ and $V - I$. This photometry is presented in Table 2, along with the companions' color excesses, based on their spectral types and the intrinsic color calibration of Johnson (1966).

Blue spectra of the companions have been obtained on IIaO plates with three different telescopes and dispersions: (*a*) 78 Å mm^{-1} with the 183-cm telescope at Victoria (VI), (*b*) 128 Å mm^{-1} with the 91-cm telescope at Kitt Peak (KP), and (*c*) 200 Å mm^{-1} with the 152-cm telescope at Cerro Tololo (CT). These spectra were used both for classification and for radial velocities. Classification was done relative to standard stars observed with the same equipment, using the criteria of the Kitt Peak Spectral Atlas (Abt *et al.* 1968). The radial velocities were measured on a Grant comparator and show an external error of ± 15 km s^{-1} (σ) (Kitt Peak) and ± 5 km s^{-1} (Victoria).

Table 3 gives the carbon star's brightest apparent visual magnitude and magnitude range (from our photometry unless otherwise indicated), the companion's spectral type and absolute magnitude (using Blaauw's 1963 calibration), and the radial velocities of the two stars. Sources are denoted by letters: A, AAVSO magnitude estimates (Mayall 1973) (these have been converted to V magnitudes through a comparison of the light curves and our interpositioned photometry); E, Eggen (1972); F, Franz and White (1973); G, Gordon (1968); M, Mendoza and Johnson (1965); W, Wilson (1953). The C star velocities either are taken from Sanford (1944) (denoted by his quality parameter: *a*, ± 1 km s^{-1}, to *d*, ± 6–8 km s^{-1}; *e*, from classification dispersion spectra), or were measured on Richer's (1971) near-infrared 124 Å

TABLE 3

Summary of Observational Data and Derived Absolute Magnitudes

Star	V(max), C Star		ΔV, C Star		Spectrum of Companion		M_V of Comp.	Radial Velocity: C Star		Radial Velocity: Companion		M_V, C Star	Wt
UV Aur........	7.4	F	3.2	F	B9 V	KP	−0.1	−10	a	−17	KP	−3.6	10
−26° 2983......	8.55		...		A5 V	CT	+1.8	+23	e	...		−2.4	10
								−6	CT	...			
SZ Sgr.........	8.4		...		A7 V	CT	+2.0	+19	b	...		−1.4	10
SU And........	8.2		...		F0 V:	VI	+2.4	−6	b	−6	VI	−2.2	9
								−11	CT				
HD 75021......	7.1		0.1	M	K1 III	G,E	+0.8	+11	a	*		+0.3	8
						CT							
TU Tau........	8.3		0.2		A2 III:	CT	−0.6	−24	c	...		−3.9	8
						KP	*	−19	CT				
W CMa........	6.55		0.9		B2 V	KP	−2.5	+21	d	+19	G	−4.7*	7
						CT							
SV Cyg........	8.4	A	0.5	A	K1 III	KP	+0.8	−8	c	−15	KP	−0.5	7
MSB 64........	9.5		...		A6 IV:	CT	+1.5	−17	c	+1	VI	−0.7	7
						VI		+4	CT				
HD 34467......	9.2		...		...		+2.1	+15	d	...		−1.6	4
MSB 41........	9.5		...		G6 III	G	+0.4	−11	e	+9	VI	−0.9	4
										+21	G		
cp. 2........	...		...		K	VI	...	...		+1	VI	...	..
HD 209596.....	10.2		...		F8 III–V	G	+1.0	−18	c	+1	VI	−1.8	3
						VI	or					or	
							+4.0					+1.2	
UV Aql	8.4		...		G4 V:	CT	+1.8*	+21	b	...		−2.9	3
X Sge..........	8.4		...		F2 V	VI	+2.8	+26	e	+3:	VI	−1.8	2
								+32	CT				
RY Mon.......	7.9		1.5	A	F3 IV	CT	+2.	+2	c	...		−2.4	..
								+4	CT				
RZ Peg........	8.2	A	4.0	A	F9 V	CT	+4.2	−27	d	...		+0.1	..
								−21	CT				
MSB 73........	10.3		...		F6 III–V	G	+1.0	−13	b	...		−1.4	..
							or					or	
							+3.5					+1.1	
V Hya.........	6.7	A	2.4	A	K0 III:	G	+0.8	−8	G	...		−4.1	..
T Dra.........	9.6	A	2.5	A	K2 III–IV	KP	+1.	−23	a	−84:	KP	−0.2	0
U Cam.........	7.2	A	0.6	A	B8 V	KP	0.	−3	c	−35	KP	−2.4	0
U Cyg.........	7.1	A	3.5	A	G2 III	KP	+0.4	+13	a	−25	KP	−0.4	0
RS Cyg........	7.2	A	0.7	A	B0.5 Ib	KP	−6.1	−50	a	−14	KP	−6	0
										−2	W		
cp. 2.........	...		...		K7 II	KP	−2	...		−18	KP	−4	..
MSB 31*.......	9.0		...		A6 III–V:	G	+1.9	+4		...		+0.1	..

* See text.

mm^{-1} spectra (CT). These velocities were determined on a system devised by the authors which is applicable to these low-dispersion spectra. Measurements of standards (Sanford's *a*-quality carbon stars) result in an internal probable error of the mean of 4 km s^{-1} for about a dozen lines and an external error of ± 10 km s^{-1} (σ). The last two columns of Table 3 give the calculated brightest absolute visual magnitude of the carbon star, based on the preceding data where available, and assuming the reality of the binary system, plus the authors' confidence level, on a scale from 0 to 10, in these derived absolute magnitudes. This is a combination of the confidence level of a physical connection between the two stars and the reliability of the companion's luminosity class. The entries in Table 3 have been rearranged in order of decreasing confidence level.

III. DISCUSSION OF INDIVIDUAL SYSTEMS

a) *UV Aurigae*

The spectral type of the 3".4 distant companion is B9 V, in excellent agreement with Gordon's (1968) type of B8.5 V. Franz and White (1973) have measured $V = 10.92$ and $B - V = 0.12$ for the companion; this agrees well with our V value but is bluer by 0.09 mag. The Q index [$Q = (U - B) - 0.72(B - V)$] corresponding to the B9 spectral type points to the star being above the main sequence, while the Hβ index indicates an absolute magnitude of -1.5 (Strömgren 1966). As these data could have been contaminated by the carbon star, an absolute magnitude of -0.1 has been adopted. Since the velocities agree reasonably well and are significantly different from the expected galactic field velocity, there is no reason to suppose that these stars do not form a physical pair. The carbon star absolute magnitude is variable between -3.6 and -0.4. The period of this variability is approximately 390 days.

b) *−26° 2983, SZ Sagittarii, TU Tauri*

These stars with composite spectra have been discussed by Richer (1972), and no further observations have been obtained. It is interesting to note, however, that both SZ Sgr and TU Tau show a feature at $\lambda\lambda$4173–4178, indicating that this may be from the carbon star spectrum, and not the luminosity-sensitive blend in the companion as suggested by Richer. If so, the luminosity class assigned to the companion of TU Tau must be changed from III to V. Thus the absolute magnitude of TU Tau is either -3.9 or -2.1.

c) *SU Andromedae*

The FO spectral type is based on two medium-well to weakly exposed spectra. As these make it rather difficult to determine the luminosity, class V has been assumed, based mainly on the width of the Balmer lines. Because of the excellent agreement of the velocities, this system seems to be on a solid basis.

d) *HD 75021*

The companion's spectral type is a compromise of Gordon (1968), Eggen (1972), and several Cerro Tololo low-dispersion spectra. Proper motion data for this double agree in declination [$-0".010$ and $-0".008 \pm 0".013$ (σ)] but not in right ascension ($-0".028$ and $+0".002 \pm 0".013$) (SAO Catalog 1966). Gordon (1968) says the radial velocities agree to within the measurement errors, but the galactic velocity gradient in this direction is very small and hence this datum does not carry much positive weight.

e) *W Canis Majoris*

Despite the large separation of the two stars (158"), there are several reasons for supposing their physical proximity. The spectral type of the companion is B2 V, given by several spectra and confirmed by the Q-value (-0.69) as well as the luminosity indicated by the Hβ index, and not B5 as given by Gordon (1968). The galactic field radial velocity at the distance of this star is $+37$ km s^{-1}, significantly different from both the B star itself ($+19$ km s^{-1}) and the C star ($+21$ km s^{-1}) which agree quite well. Since the solar motion component in this direction contributes $+18$ km s^{-1} to these velocities, it is clear that the B star motion differs greatly from the galactic field. Furthermore, the declination components of the proper motions agree very well [$+0".023$ and $+0".019 \pm 0".020$ (σ)], although the right ascension components are somewhat discordant ($-0".036$ and $+0".017 \pm 0".027$) (SAO Catalog 1966).

f) *SV Cygni*

The radial velocity data for these stars cannot be used to verify the reality of this system as both of the velocities agree well with the galactic field velocity at the distance of the companion and the system is in a direction ($l = 83°$) where the velocity is rather insensitive to distance. Since the derived C star absolute magnitude is reasonable and because there are no contradictory data, this system cannot be ruled out as real.

g) *MSB 64*

The luminosity classification of the companion is based on the width of the Balmer lines; if the star is on the main sequence, the absolute magnitude will be fainter by 0.4 mag. The Victoria radial velocity agrees well with the infrared C star velocity but not with Sanford's *c*-quality blue velocity.

h) *HD 34467*

The *UBV* photometry is consistent with spectral types B9 V, A8 V, and gF, while the Hβ value is compatible with the B9 V and A8 V types only. If the A8 V type is assumed (this requires the least reddening and sets the faint limit to the C star), the carbon star would have an absolute magnitude of -1.6 if the system is real.

i) *MSB 41*

Sanford's (1944) C star velocity does not agree well with either of the companions, but its poor quality makes this of low weight.

j) *HD 209596, MSB 73*

The C star absolute magnitudes for these doubles are based on Gordon's (1968) spectral types for the companions and the present improved photometry. The velocity for HD 209596's companion is based on but four broad lines, these agree fairly well, however.

k) *UV Aquilae*

The spectral type of the companion is based on a rather weak plate; hence the uncertain luminosity class. The photometry is consistent with a K2 giant and supergiant but only marginally acceptable as a main-sequence star, and then as a late K dwarf.

l) *X Sagittae*

The photometry is indicative of a slightly later spectral type for this companion than is given by the spectrum. The weakness of the Ca I λ4226 line and the G-band is strongly supportive of the earlier type however; perhaps the star is metal poor. Sanford's (1944) C star velocity is confirmed by the presently measured infrared velocity, while the companion's velocity seems to be significantly different. This system does not appear to be real.

m) *RY Monocerotis*

The photometry for this companion is consistent with an unreddened F6 V star, somewhat later than is indicated by the available spectrum, which has been given the greater weight. Should this system be real

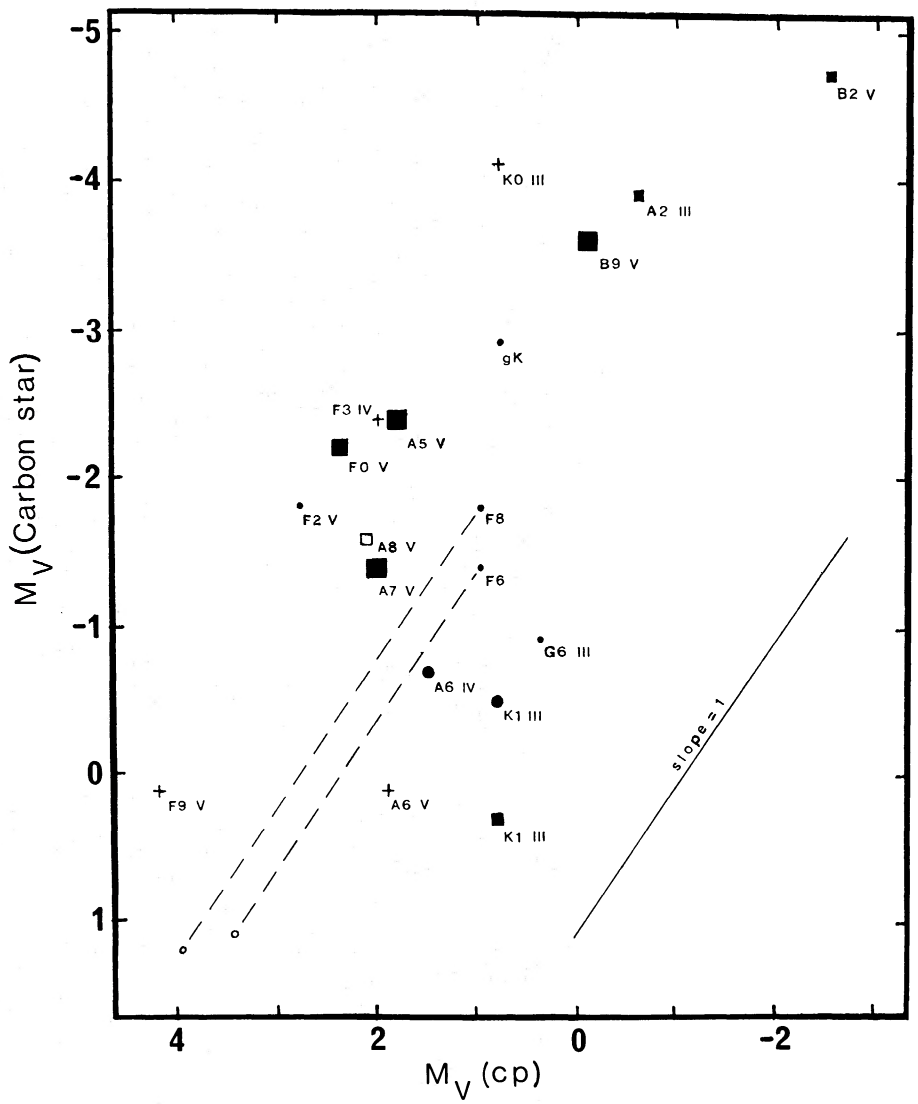

FIG. 1.—Relation between the absolute magnitudes of the carbon stars and their companions. The symbol sizes indicate the relative weights.

the photometric spectral type would set a faint limit to the C star absolute magnitude of −0.9.

n) *RZ Pegasi*

A radial velocity for the companion would be most valuable here as the suggested C star absolute magnitude would be among the faintest known for N stars. It is interesting to note that the carbon star shows emission in the infrared Ca II triplet (Richer 1971).

o) *V Hydrae*

VRI photometry of this double gives ($V - R$, $V - I$) colors for the companion of (0.81, 1.56), consistent with a spectral type of K1 or K2 III, or K0 III:, the spectral type given by Gordon (1968). If this system is real, V Hya is both the reddest and intrinsically brightest star investigated here.

p) *MSB 31*

The magnitude data for the companion to MSB 31 are based on a photographic magnitude by Sanford (1940) of 11.0 and Gordon's (1968) spectral type. Luminosity class V has been assumed in Table 3. The small separation of this pair lends credibility to the reality of this system.

q) *T Draconis, U Camelopardalis, U Cygni, TS Cygni*

The large velocity differences between the carbon stars and the suspected companions rule out these doubles as real systems.

IV. DISCUSSION

The relation between the absolute magnitudes of the C stars and their companions is shown in Figure 1. The faint limits shown are at least partially affected by observational selection. Nonetheless, there seems to be some indication of a trend in the sense that the early A and B type companions are associated with the brightest C stars, and the higher weighted late type giants are associated with fainter C stars. Since the early type stars are expected to be younger (on average) and their evolved C type companions therefore more massive (initially at least), this may be taken as a mild indication for a mass-luminosity relation for carbon stars.

If we delete the two R stars and apply the weights indicated in the last column of Table 3, we find that the mean absolute magnitude of the remaining 13 N stars is -2.3 ± 1.1 (σ). As there is nothing obviously peculiar about this set of stars (other than having companions) they can be assumed to be a typical sample of N stars.

Since most of the energy from carbon stars is radiated in the infrared, their visual absolute magnitudes are not as physically meaningful as their bolometric absolute magnitudes. To properly calculate the bolometric corrections, however, one needs

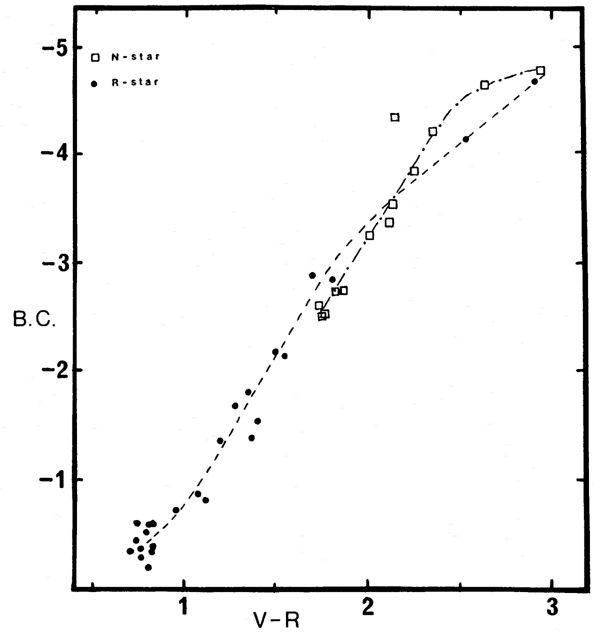

FIG. 2.—Calculated bolometric corrections as a function of $V - R$ for R and N Stars.

photometric information extending far into the infrared, and such data exist for but a few dozen carbon stars (Mendoza and Johnson 1965). Fortunately, their data show that there exists a good correlation between the calculated bolometric corrections and the $V - R$ color index for both R and N stars. These relations are shown in Figure 2. Since we expect that the stars in Figure 2 are reddened by different amounts, it is

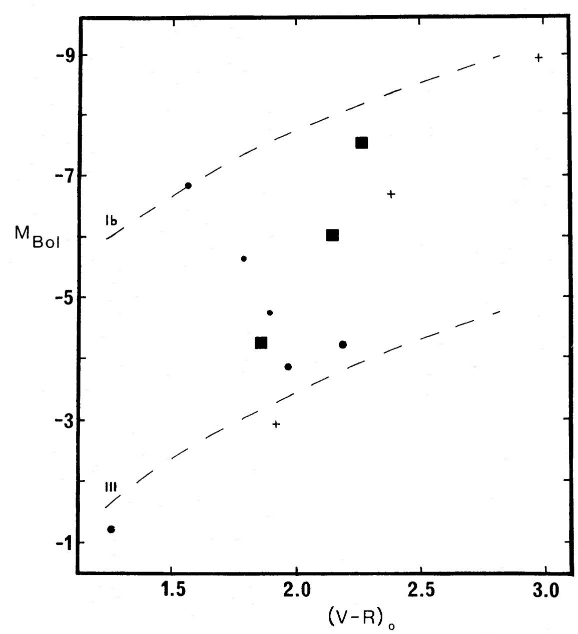

FIG. 3.—Derived carbon star bolometric absolute magnitudes as a function of intrinsic $V - R$ color. The symbol sizes indicate the relative weights. The normal giant and supergiant branches from M0 to M6 are also shown.

surprising at first that the correlation is as tight as is indicated. The effect of interstellar reddening is, however, not only to make the observed colors redder, but also to increase the ratio of the nonvisual to visual flux (since most of the flux for these cool stars is in the infrared), thus causing an overestimate of the bolometric corrections based on the reddened colors. Hence reddening will cause a star to move more or less along the lines of Figure 2, rather than across them, retaining the tightness of the relation.

To derive bolometric corrections for the stars in this study, the observed $(V - R)$ colors, where available (Table 2 and Mendoza and Johnson 1965) were corrected for the reddening shown by the companions (Table 2, last column) according to $E(V - R) = 0.75\ E(B - V)$. The bolometric corrections were then read off from Figure 2. These are expected, in most cases, to be good to a few tenths of a magnitude. The resulting bolometric absolute magnitudes have been plotted in Figure 3 versus the deduced intrinsic $(V - R)$ colors. For reference the normal giant and supergiant branches from M0 to M6 are also included (Blaauw 1963; Johnson 1966). It is thus apparent that the late-type carbon stars are not confined to a narrow luminosity range, but in fact populate a wide band (about 4 mag wide) corresponding to the region between the normal giant branch and the supergiants.

The authors would like to extend their thanks to the Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory and the Dominion Astrophysical Observatory for providing observing time, and to members of their staffs for their friendly assistance.

REFERENCES

Abt, H. A., Meinel, A. B., Morgan, W. W., and Tapscott, J. W. 1968, *An Atlas of Low-Dispersion Grating Stellar Spectra* (Tucson: Kitt Peak National Observatory).
Baumert, J. H. 1972, Ph.D. thesis, Ohio State University.
———. 1974, *Ap. J.*, **190**, 85.
Blaauw, A. 1963, in *Basic Astronomical Data*, ed. K. Aa. Strand (Chicago: University of Chicago Press), p. 383.
Catchpole, R. M., and Feast, M. W. 1973, *M.N.R.A.S.*, **164**, 11P.
Crull, H. E. 1972, private communication.
Dickens, R. J. 1972, *M.N.R.A.S.*, **159**, 7P.
Eggen, O. J. 1972, *Ap. J.*, **174**, 45.
Feast, M. W., and Lloyd Evans, T. 1973, *M.N.R.A.S.*, **164**, 15P.
Franz, O. G., and White, N. M. 1973, *Bull. AAS*, **5**, 43.
Gaustad, J. E., and Conti, P. S. 1971, *Pub. A.S.P.*, **83**, 351.
Gordon, C. P. 1968, *Pub. A.S.P.*, **80**, 597.
Harding, G. A. 1962, *Observatory*, **82**, 205.
Hartwick, F. D. A., and Hesser, J. E. 1973, *Ap. J.*, **183**, 883.
Iriarte, B., Johnson, H. L., Mitchell, R. I., and Wisniewski, W. K. 1965, *Sky and Tel.*, **30**, 21.
Johnson, H. L. 1966, *Ann. Rev. Astr. and Ap.*, **4**, 193.
Mayall, M. W. 1973, private communication.
Mendoza, E. E., and Johnson, H. L. 1965, *Ap. J.*, **141**, 161.
Richer, H. B. 1971, *Ap. J.*, **167**, 521.
———. 1972, *Ap. J. (Letters)*, **172**, L63.
Sanford, R. F. 1940, *Pub. A.S.P.*, **52**, 408.
———. 1944, *Ap. J.*, **99**, 145.
Smithsonian Astrophysical Observatory, 1966, *Star Catalog* (Smithsonian Publication 4652).
Strömgren, B. 1966, *Ann. Rev. Astr. and Ap.*, **4**, 433.
Vandervort, G. L. 1958, *A.J.*, **63**, 477.
Westerlund, B. E. 1964, in *IAU Symposium 20, The Galaxy and the Magellanic Clouds*, ed. F. J. Kerr and A. W. Rodgers (Canberra: Australian Academy of Science), p. 239.
Wilson, R. E. 1953, *General Catalogue of Stellar Radial Velocities* (Washington: Carnegie Institution of Washington).
Yamashita, Y. 1972, *Ann. Tokyo Astr. Obs.*, **13**, 19.

B. Ingemar Olson and Harvey B. Richer: Department of Geophysics and Astronomy, University of British Columbia, 2075 Westbrook Place, Vancouver, B.C. V6T 1W5, Canada