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Absolute magnitudes of carbon stars from Hipparcos parallaxes*

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Abstract. Hipparcos trigonometric parallaxes and photometric data for about 40 bright carbon stars have been analysed. Individual absolute visual and bolometric magnitudes, normal color indices $(B-V)_0$, absorption values and distance moduli were determined. By comparison with stellar evolutionary tracks for initial mass $1 \leq M/M_{\odot} \leq 4$ it is found that the majority of CH- and R-stars are on the giant and subgiant branches, but N-stars occupy a region $-4 < M_V < -1$ and $1.6 < (B-V)_0 < 3.6$ and correspond to an advanced stage of thermally pulsing asymptotic branch giants. Previous absolute magnitude estimates, especially those from statistical parallaxes, are confirmed by Hipparcos. Using Hipparcos parallaxes and proper motions, three multiple stars with a carbon star component are examined. Hipparcos data confirms a physical link between W CMa and HD 54306 (B2V), both probable members of the association CMa OB1. Some stars are located below the subgiant branch for the mass $1M_{\odot}$ and a number of the N stars are below the theoretical limit for carbon stars on the AGB.

Key words: stars: carbon – stars: fundamental parameters

1. Introduction

Until Hipparcos, the distance determination for galactic carbon stars was a difficult problem. Albeit some authors (see e.g. Groenewegen et al., 1992 or Claussen et al., 1987) had published extensive lists of carbon star distances, especially for N-type stars, the determination was very indirect – it was based on an assumption that all N-type stars would have the same luminosity with a value estimated from theoretical evolution calculations. The specific values of luminosity used by various authors also are in variance. Distances to CH- and R-stars (where such an assumption is obviously incorrect), were known still more vaguely.

But mainly the aim is just the opposite – to know the distance in order to determine the absolute magnitude of a star. Before Hipparcos our knowledge about the mean absolute magnitudes of carbon stars had relied mostly on statistical parallaxes based on proper motion and radial velocity measurements, as well as theoretical considerations. Data for individual objects, however, were very scanty, consisting of same uncertain hints from binaries containing carbon stars, possible members of star clusters, and the Wilson-Bappu effect. The most straightforward method, i.e. through trigonometric parallaxes, has hitherto been of little value, owing to the considerable distances even to the nearest carbon stars, and the imperfectness of previous measuring methods (see a compilation of previous data by Alksne et al.(1991)).

The situation has radically changed after the mission by the astrometric satellite Hipparcos. The mean error of about 1 mas – a characteristic value for parallaxes measured by Hipparcos – provides us with reliable distance estimates inside, say, the 0.5 kpc region around the Sun including some 100 carbon stars.

Hipparcos also supplied us with precise photometric data, giving the mean brightness estimate from ~ 100 observations of each star, a circumstance, which because of the variability of carbon stars, is of special value. Here, a problem specific to carbon stars – stars with a peculiar spectral energy distribution –, to accurately correct ground-based photometry for atmospheric extinction, is irrelevant for Hipparcos data.

In the following, Hipparcos trigonometric parallaxes and magnitudes for a sample of about 40 bright carbon stars, mainly from our proposal list, documented in the Hipparcos Input Catalogue as No. 22 (Turon et al.1992, Vol.1 p.62) are analysed and their absolute magnitudes deduced (Sect. 2). Further, in Sect. 3, Hipparcos data for some wide multiple systems containing carbon stars are analysed to clarify the question whether they are optical or physical. In Sect. 4 the obtained absolute magnitudes and normal color indices are discussed and compared in the H-R diagram with evolutionary tracks from theoretical calculations. Some curious specimens are singled out and proposals put forward how to remedy the apparent contradictions with modern stellar evolution theory.

2. Determination of absolute magnitudes

2.1. *Visual absolute magnitudes M_V and absorption A_V*

To determine visual absolute magnitudes M_V, corresponding visual V magnitudes in the Johnson UBV photometric system were taken from the Hipparcos Catalogue (ESA 1997). These V magnitudes mostly are deduced from a careful reduction of

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[*] Based on observations made with the ESA Hipparcos astrometry satellite

Hipparcos observations, done by the authors of that catalogue and correspond to the median brightness value from about 100 measurements for each star. Thus, Hipparcos V values must be considered as the most accurate amongst existing median brightness measurements for variable carbon stars. However, for carbon stars with extreme colour indices, the transformations used in the reduction of Hipparcos photometric measurements into V magnitudes listed in the Hipparcos Catalogue may be a source of error in the determination of V and, hence, of M_V.

For determination of individual absolute magnitudes, only certain stars can be selected, because, for instance, absolute magnitude is not defined for negative parallaxes. Small parallaxes with great errors are also of little value as disturbing the general picture. Intuitively, the most natural seems the selection by a relative parallax error. The choice of a precise cut-off value is somewhat arbitrary and we used intuitively the most natural one $\pi > \sigma_\pi$. It turns out that selection by such condition also automatically separates the stars with $\pi > 1$ mas. Thus, about 40 such stars are left in our sample. The selection criterion $\pi > \sigma_\pi$ prevents us from calculating average absolute magnitudes, because of biases introduced by such a selection. Therefore we restrict ourselves to a comparison of individual absolute magnitudes with evolutionary tracks.

The amount of interstellar absorption in the V magnitude was calculated using the three-dimensional galactic interstellar absorption model by Arenou et al. (1992). In that model the sky is divided into small tetrangles and in each of them the absorption A_V as function of distance is represented by a quadratic polynomial.

Derived visual absolute magnitudes M_V for individual stars are listed in Table 1 for carbon stars of spectral type N, and in Table 2 for CH- and R-type stars. In the same way, the tables give 1σ limits of M_V – M_{V-} and M_{V+} calculated with parallaxes $\pi - \sigma_\pi$ and $\pi + \sigma_\pi$ correspondingly. Some stars in Table 1 (especially with amplitude $H_p > 1$) are so called "variability-induced movers" (VIMs, see ESA, 1997, Vol.1 p.185) – stars, whose photocenter moves with the same period as the brightness, an effect which may cause a systematic error in the measured parallax value. For such stars M_V in Table 1 is marked with a colon. In the last column of Table 1 the variability type of the stars is also indicated. The $(B-V)_0$ values were found from A_V using the ratio of total to selective absorption $R_V = 4.2$ (Olson 1975) for N-type stars with $(B-V)_0 > 1.6$ and in other cases, $R_V = 3.7$, as given by Straižys (1977) as characteristic for G-K giants.

There exist some carbon stars for which the catalogue only gives a crude estimate of B-V from ground-based observations, with an error $\sigma_{B-V} \approx 0.4 - 0.5$ which evidently are guessed values (frequently 0.51). For these stars we have calculated B-V from B_T and V_T according to the reduction formula used in the catalogue to find B-V for C-type stars from Hipparcos/Tycho observations. Although the error of B_T for these stars is also considerable (0.1 - 0.3 mag), B-V calculated in such a fashion is strictly related to the median brightness derived from about 100 observations for each star, in contrast to the ground-based measurements which are mostly restricted to some variability phase interval. $(B-V)_0$ values derived by us from B_T and V_T in Table 1 are marked with a colon.

2.2. Infrared absolute magnitudes M_K

Besides M_V, infrared absolute magnitudes M_K have been frequently used, especially in connection with distance determinations where it has been assumed that all asymptotic giant branch (AGB) carbon stars have the same M_K (e.g. Claussen et al. 1987). To obtain absolute magnitudes M_K, K from various sources as compiled by Gezari et al. (1993) was averaged, also including some later observations, e.g., by Kerschbaum et al. (1996). The results correspond to Johnson's K-band (2.2 μm). The value A_K/A_V= 0.126 (Cardelli et al. 1989) was adopted. M_K for individual N-type stars are listed in Table 1.

2.3. Bolometric magnitudes M_{bol}

To obtain absolute bolometric magnitudes M_{bol} of carbon stars, all existing brightness measurements in various passbands in the wavelength interval 0.36–100 μm were converted to absolute fluxes, using flux calibrations given by observers, averaged in each passband and then integrated by trapezoidal rule. IRAS fluxes (Joint IRAS Science Working Group 1986) have been color-corrected according to Table C IV.6 in IRAS Explanatory Supplement, using the mean of two adjacent color temperatures (Hacking et al. 1985). If necessary, at the long wavelength side the integration was continued drawing the black-body curve through two last wavelength points with measured flux. In calculating the amount of absorption in various passbands, the empirical reddening law by Cardelli et al. (1989) was used to find A_λ/A_V. Bolometric magnitudes were normalised taking total solar flux $f_\odot = 1.360 \cdot 10^5$ erg/s cm^2 and $m_{bol\odot} = -26.82$ mag (Allen 1973).

Bolometric magnitudes for CH- and R-stars in Table 2 can be exactly calculated only in a few cases, because infrared photometric observations in the decisive interval 0.7–3.0 μm are missing or scanty. For the CH-star V Ari $M_{bol} = -2.66 \pm 2.13$ mag and for BD $8^0 2654$: $M_{bol} = 2.09 \pm 0.88$ mag is obtained.

3. Carbon stars in wide multiples

In a case of poorly known trigonometric parallax some information about the absolute magnitude can be obtained if a carbon star forms a physical pair with some ordinary star. Such a pair must be sufficiently wide to allow photometric and spectroscopic observations of both stars separately, although the enlarged angular separation can make an embarrassment in proving the common origin of the pair. There, a knowledge of proper motions and radial velocities of the components may help. When comparing proper motions of the components it should be taken into account that for such wide pairs the influence of orbital motion on proper motion is negligible. Thus, e.g., for a pair in circular orbit with masses M_1, M_2 (in $M_\odot$), parallax π, and

Table 1. Absolute magnitudes of N-type stars

HIP	Name	π(mas)	σ_π/π	V_0	$(B-V)_0$	A_V	M_V	M_{V-}	M_{V+}	M_K	m_{0bol}	M_{bol}	Type
99	WZ Cas	1.27±0.70	0.55	5.41	2.45	1.63	-4.07	-6.64	-2.63	-9.09	3.04	-6.44	SRb
6759	R Scl	2.11 1.75	0.83	6.47	3.76:	0.10	-1.91	-5.75	-0.60	-8.59	2.29	-6.09	SRa
14930	TW Hor	2.48 0.56	0.23	5.48	2.37	0.23	-2.54	-3.10	-2.10	-7.94	2.77	-5.26	SRb
23203	R Lep	3.99 0.85	0.21	7.84	4.63:	0.24	0.84	0.32	1.26	-7.04	3.29	-3.71	M
23680	W Ori	4.66 1.44	0.31	5.73	3.24	0.37	-0.93:	-7.06	-1.90	-0.25	2.65	-4.01	SRb
26284	SZ Lep	3.63 0.98	0.27	7.51	2.16	0.15	0.31	-4.55	-0.37	0.83	4.85	-2.35	Lb:
31108	HX Gem	12.82 3.03	0.24	10.35	1.57:	0.08	5.89:	5.28	6.36				Lb:
31579	UU Aur	1.80 0.81	0.45	5.08	2.70	0.32	-3.65	-5.07	-2.80	-9.47	2.38	-6.34	SRb
38787	HD65424	1.74 0.70	0.40	7.33	2.88	0.39	-1.47	-2.71	-0.65	-7.14	4.44	-4.36	Lb:
41058	T Lyn	9.97 4.33	0.43	9.69	2.24:	0.07	4.69:	3.45	5.47	-2.05	5.63	0.62	M
48327	Y Hya	2.87 0.79	0.28	6.58	3.37	0.27	-1.14	-1.84	-0.58				SRb
49950	AB Ant	3.32 0.69	0.21	6.32	2.18	0.36	-1.08	-1.64	-0.62	-5.97	4.10	-3.29	Lb:
51821	U Ant	3.90 0.67	0.17	5.18	2.94	0.32	-1.87	-2.32	-1.49	-7.66	2.32	-4.72	Lb
52009	U Hya	6.18 0.75	0.12	4.74	2.50:	0.15	-1.31	-1.59	-1.05	-6.82	2.19	-3.86	SRb
52577	VY UMa	2.88 0.65	0.23	5.95	2.38	0.00	-1.75	-2.31	-1.31	-7.28	3.33	-4.37	Lb
62223	Y CVn	4.59 0.73	0.16	5.38	2.98	0.04	-1.31	-1.69	-0.99	-7.56	2.22	-4.47	SRb
63152	RY Dra	2.05 0.65	0.32	6.63	3.27	0.00	-1.81:	-2.64	-1.21	-8.35	3.14	-5.30	SRb
74582	X TrA	2.18 0.60	0.28	5.15	3.13	0.60	-3.15	-3.88	-2.56	-8.97	2.30	-6.01	Lb
86728	V Pav	3.32 0.83	0.25	6.40	3.07:	0.45	-1.00	-1.71	-0.44				SRa
87063	SX Sco	2.75 1.42	0.52	6.99	2.94:	0.67	-0.81:	-2.91	0.03	-6.35	3.78	-4.02	SR
95154	UX Dra	1.75 0.52	0.30	6.20	2.67	0.02	-2.59	-3.35	-2.02	-8.69	3.23	-5.55	SRa
100219	U Cyg	1.11 0.77	0.69	7.35	2.67:	0.90	-2.42:	-6.20	-0.83	-8.83	4.18	-5.59	M
109089	RZ Peg	3.54 1.36	0.38	8.32	2.63:	0.15	1.07:	-0.06	1.81	-4.36	5.44	-1.81	M
117245	TX Psc	4.29 0.93	0.22	4.88	2.49	0.07	-1.96	-2.49	-1.53	-6.91	2.36	-4.48	Lb

Table 2. Absolute magnitudes of CH- and R-stars

HIP	Name	π(mas)	σ_π/π	V_0	$(B-V)_0$	A_V	M_V	M_{V-}	M_{V+}
			CH-stars						
10472	V Ari	1.45±1.42	0.98	8.40	2.08	0.12	-0.79	-9.21	0.69
44032	HD76396	2.64 1.39	0.53	8.83	1.08	0.07	0.94	-0.68	1.86
53763	BD42^{0}2173	5.29 1.47	0.28	9.94	1.29	0.08	3.56	2.85	4.09
62827	BD8^{0}2654	5.30 2.15	0.41	9.27	1.35	0.09	2.89	1.76	3.65
102706	HD198269	3.16 1.11	0.35	7.97	1.21	0.20	0.47	-0.58	1.18
			R-stars						
54806	HD97578	31.18 14.06	0.45	10.11	1.45	0.03	7.58	6.26	8.40
84266	HD156074	2.95 0.65	0.22	7.50	1.12	0.10	-0.15	-0.69	0.28
86927	BD17^{0}3325	4.26 1.11	0.26	8.49	1.11	0.22	1.63	0.93	2.17
89783	FO Ser	2.74 1.21	0.44	7.42	1.60	1.01	-0.39	-2.27	0.68
105241	BD2^{0}4338	7.25 2.16	0.30	9.67	1.30	0.14	3.98	3.19	4.56

angular separation ρ the orbital motion is

$$\mu \leq \sqrt{\frac{\pi^3(M_1+M_2)}{\rho}} \quad ''/\mathrm{yr},$$

an insignificant quantity in comparison with a usual proper motion at the appropriate distance for stars in Table 3.

There are three possible multiples with a carbon star in our sample (Table 3).

BD 8^{0}2654A

BD 8^{0}2654 is a triple system and there is some confusion with the identification of the component which in fact is the carbon star. HIP pointed out component A which is the brightest of the triple while Stephenson (1989) stressed that the carbon star is the faintest one – component C. The question does not reduce simply to interchange of designations, because coordinates of the components in both sources are in agreement. We relied on the HIP choice because the A component is the reddest one. The HIP identification of component A with HD 111908 is also questionable, because on unsensibilized plates (as used compiling HD), A and B appear with equal brightness as deduced from their $B-V$ values in HIP. In any case, parallaxes and proper motions as given in Table 3 bear witness that the triple is an optical system.

Table 3. Wide pairs with carbon stars

HIP	Name	V	$B-V$	π(mas)	$15\mu_\alpha\cos\delta$	μ_δ(mas/yr)	$\rho('')$
62827	BD8^{0}2654A	9.36	1.38	5.30±2.15	-15.28±1.85	30.44±1.37	
62830	BD8^{0}2654C	11.06	1.10	17.32 7.65	-21.36 5.52	16.27 4.53	38.2
62831	BD8^{0}2654B	9.48	1.07	6.83 2.31	-39.26 1.94	17.00 1.51	33.4
33413	W CMa	6.65	2.55	0.44 0.82	-6.22 0.81	2.82 0.63	
34395	HD54306	8.77	0.03	1.03 1.22	-6.34 1.13	1.55 0.92	158.8
43093	UZ Pyx	7.29	2.09	-0.11 0.81	-6.90 0.55	2.11 0.60	
43088	HD75022	7.63	1.44	-0.41 0.82	-6.18 0.55	2.46 0.61	110.2
100219	U Cyg	8.25	3.31	1.11 0.77	-1.53 0.73	0.99 0.59	
100230	HD193700	7.84	0.80	3.64 0.72	13.10 0.77	5.53 0.54	65.2

W CMa

In the case of W CMa overlapping 1σ intervals of the proper motion components of the pair W CMa and HD54306 point towards a common origin of both stars. Difference in radial velocity between the components is only 4 km/s (Turon et al. 1992). At mediocre measurement precision this may be regarded as an affirmative indication. In the vicinity of W CMa also other early type stars are found (besides HD54306) which had been regarded as forming the association CMa OB1 and, therefore, some authors (e.g., Herbst et al. 1977) considered the carbon star to be a member of the association also. The fact that W CMa in red light illuminates a dust cloud – a fragment of the dust complex in which the association is embedded, can serve as an argument. According to Claria (1974) the distance modulus of CMa OB1 is $V_0 - M_V = 10.2$ mag. The companion star has spectral class B2 V (Turon et al. 1992) and thus, E(B-V)=0.28 mag and then, according to the calibration of the relation (M_V - $(B-V)_0$) for main sequence stars by Straižys & Kuriliene (1981), follows $M_V = -2.5$ mag. The observed difference $\Delta V = 2.12$ mag then gives for W CMa $M_V = -4.6$ mag, but there is a need for some correction because stars with so different color indices affected by the same amount of interstellar absorption should have different A_V. Attributing to the carbon star the dependence of the reddening ratio $E(B-V)_{star}/E(B-V)_{B0}$ for normal color index $(B-V)_0$, as given by Straižys (1977), and taking for it $A_V/E(B-V)$=4.2 (Olson 1975) one obtains that W CMa has 0.13 mag smaller absorption. So it has $M_V = -4.5$ mag and in comparison with other stars in Table 1 is overluminous. With the distance modulus noted before it has $m_{0bol} = 3.53$ mag and, thus, $M_{bol} = -6.8$ mag. Given the high luminosity, a corresponding mass value must be ascribed to W CMa as companion to HD54306 and a member of CMa OB1. According to Straižys & Kuriliene (1981) B2 V stars have mass $\sim 10\ M_\odot$ and so W CMa should have a somewhat larger mass, which is unusual for a carbon star.

UZ Pyx

In the third case, where the companion is a K2/3 III star (Turon et al. 1992), parallaxes are negative, but 1σ intervals of proper motions overlap. But relying only on this fact it is premature to suppose the physical connection between both stars for there are some inconsistencies. The absolute magnitude of K giants as a function of the spectral class is somewhat indefinite because of the steepness of the giant branch. Supposing even the maximal admissible absolute magnitude $M_V \sim -2$ mag for a star of spectral class K2/3 III (Straižys & Kuriliene, 1981), the distance to a star with V=7.6 mag and A_V=1.8 mag (according to the tables of Arenou et al., 1992) would be only ≈ 0.8 mag, and the linear separation between both stars 0.4 pc – too large to consider the pair as physical. It is also doubtful whether Hipparcos could have found a negative parallax at such a distance. Possibly, HD 75022 might be of luminosity class II or I, which makes the separation in case of a physical pair even larger. Thus, from Hipparcos data one cannot draw a definite conclusion on the possible existence of a physical pair.

U Cyg

Hipparcos data also reveal that the Mira type variable U Cyg and its companion – a giant with spectral type G0 – constitutes an optical pair. As is evident from Table 3, the error interval for parallaxes overlap only at a 2σ limit, and proper motions of both stars are very incompatible.

4. Discussion of the results

4.1. *Comparison with previous results of absolute magnitude determinations*

It is interesting to compare the absolute magnitudes given in Tables 1 and 2 as calculated from Hipparcos trigonometric parallaxes with the results of previous determinations.

4.1.1. N-type stars

Individual M_V values found above may be compared with the results obtained from statistical parallaxes. Thus, one of the most accurate calculations by Mikami (1986, AGK3 proper motions treated by maximum likelihood method) has given $\overline{M}_V = -1.6 \pm 0.6$ mag (the mean value for classes C4-C7), which is in accord with the results in Table 1 (for earlier absolute magnitude determinations see Alksne et al. (1991)).

In comparing results for individual objects, a couple of carbon stars may be used, whose membership in open clusters is confirmed by radial velocities. Thus, from UBV photometry by Eggen (1974) and Hartwick & Hesser (1974), one can deduce for QT Pup (a member of the open cluster NGC 2477) $M_V = -1.1$ mag. Similarly, for V532 Cas in NGC 7789 it can be found $M_V = -1.7$ mag (Alksne et al. 1991). These values are in the interval allowed by the determinations from Hipparcos data.

One star in Table 1 – TW Hor – also belongs to those carbon stars which have been proposed to be cluster members. Bouchet & The (1983) claimed that this bright N-type star may possibly be a member of the sparse open cluster NGC 1252. Hipparcos data now allow to cast some light on this statement. Bouchet and The found from UBV photometry a cluster distance modulus 8.49±0.13 mag but from spectroscopic parallaxes 8.22±0.22 mag. These numbers are within a 1σ interval, when comparing with the distance modulus for TW Hor found from Hipparcos data. The absolute magnitudes $M_V = -2.66$ mag and bolometric – $M_{bol} = -5.21$ mag – found by Bouchet & The for TW Hor by using a mean value of the both distance moduli which they found, are in very good agreement with our numbers in Table 1. Thus, the absolute magnitude from Hipparcos data confirms the magnitude of TW Hor deduced from the assumption that the star is a member of the cluster.

4.1.2. CH-stars

The individual values take up the interval $-0.8 < M_V < 3.6$ mag (Table 2). This can be compared with an analogous interval $-2.7 < M_V < 2.2$ mag found by Sanford (1944) from the intensity of the interstellar sodium doublet in the spectra of some CH-stars. The compilation by Alksne et al. (1991) of M_V determinations for five CH-stars – members of the globular cluster ω Cen – gives $-2.6 < M_V < 0.0$ with the mean $\overline{M}_V = -1.6 \pm 0.5$ mag. The mean value $\overline{M}_V = -1.0 \pm 0.8$ obtained by Mikami (1986) from statistical parallaxes is within the limits of Table 2. It should be admitted, that in earlier determinations of mean absolute magnitudes, the samples used were small and corrections for possible bias were ignored. Thus, the results from Hipparcos yield absolute magnitudes for CH-stars 1 – 2 mag fainter to compare with the previous investigations.

It is difficult to say something definite about previous determinations of absolute magnitude of R-stars, because the separation between CH- and R-types formerly was not made as distinctly as can be done at present, when from McClure's (1997) radial velocity measurements it has become known that R-stars (contrary to CH-stars) have a lower rate of occurrence in binaries. For CH- and R-stars, we have not determined M_{bol} because of scarcity or lack of infrared data. It was noticed, that the R-star FO Ser has a great radiation excess in the far infrared (at 100 μm) (Joint IRAS Science Working Group, 1986)

4.1.3. Carbon stars in the Magellanic Clouds

It is useful to contrast the results for carbon stars in the Galaxy with those for Magellanic Cloud objects. According to the luminosity function of carbon stars in the LMC constructed by Groenewegen & de Jong (1993) as a summary from various observations, those carbon stars have bolometric magnitudes $-3.5 > M_{bol} > -6.5$ mag with peak magnitude $M_{bol} = -4.9$ mag. The mean K-magnitude is $\overline{M}_K = -8.1$ mag (Frogel et al. 1980). These values are, in fact, the same as we have found for galactic carbon stars. As the LMC has about 2.5 times lower metal content Z than the Galaxy, stellar evolution theory predicts a greater luminosity for stars in TP AGB phase with the same initial mass (see Marigo et al. 1996), and one must ask for the cause of equality in luminosity. But the same calculations with different Z have shown that the mass distribution function of carbon star progenitors in the Galaxy is skewed towards larger values than in Magellanic Clouds. Thus, the identical luminosity can be explained by a greater mean initial mass of carbon stars in the Galaxy.

4.2. General appearance of carbon stars on the H-R diagram

It is valuable to compare observational positions of carbon stars on the H-R diagram with stellar evolutionary tracks. For this purpose tracks for initial mass 1, 2, 3, 4, 5 $M_\odot$ calculated by Charbonnel et al. (1996) and Schaller et al. (1992) were used.

For carbon stars in the solar neighbourhood, it is natural to use the same value of principal abundance parameters as obtained for the Sun itself. So, we chose tracks calculated with standard values Z=0.02 and Y=0.28 which are very close to the numbers found by Sackmann et al. (1993) for the initial Sun.

The translation of evolutionary tracks from a theoretical H-R diagram $(M_{bol}-T_{eff})$ to an observational one $(M_V-(B-V)_0)$ is done by using bolometric corrections compiled by Straižys & Kuriliene (1981) and the relation between T_{eff} and $(B-V)_0$ for luminosity class III, taken from the same source. This is justified because the tracks are calculated with the same initial abundances as for the normal-composition giants in the solar vicinity. To fix the location of N-type stars from Table 1 in the theoretical HR diagram, we used the compilation of effective temperatures for the 30 brightest N-type stars utilized by Lambert et al. (1986) in an abundance analysis of carbon star atmospheres. For the stars common to both samples T_{eff} values were taken directly, for others it was found by calculating (for the Lambert et al. sample) regression lines between T_{eff} and all infrared color indices resulting from I,J,H,K,L magnitudes. Those with correlation coefficients > 0.7 were used to calculate T_{eff} for the remainder of stars. The resulting picture for stars in Tables 1 and 2 is displayed in Fig. 1 (some outlying stars are outside the frame). The tracks end at the phase of the first thermal pulse on the AGB.

Fig. 1 shows that R- and CH-stars occupy the giant and subgiant regions, as anticipated from evolutionary theory (with two exceptions, see 4.3). It is evident that all R- and CH-stars in our sample are lying on tracks for initial masses less than $3M_\odot$. In Fig. 1, there is a gap between the region of N-stars ($(B-V)_0 < 1.9$ mag) and the calculated boundary (at $(B-V)_0 \sim 1.6$) of the onset of thermal pulses. This validates the theoretical prediction that some time period in the TP AGB phase must pass before an oxygen star transforms into a carbon star.

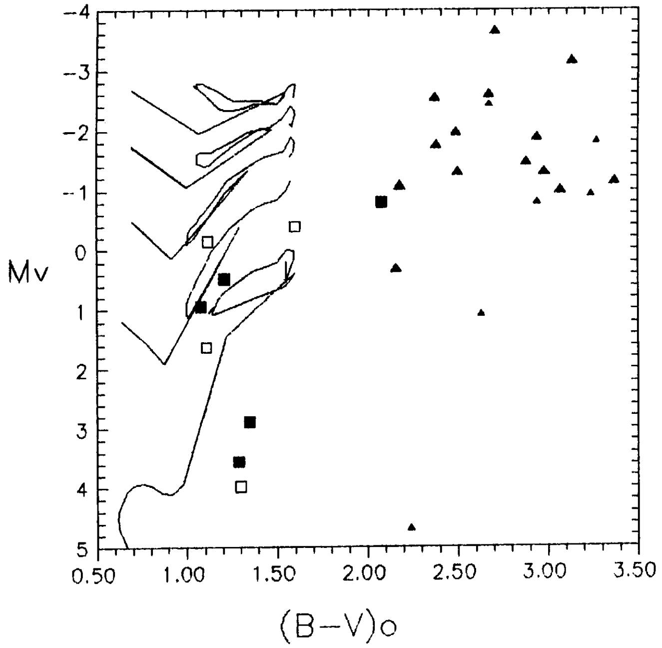

Fig. 1. Observational H-R diagram for carbon stars. Filled squares - CH-stars, open squares - R-stars, triangles - N-stars. Small triangles - variability induced movers (see text). The evolutionary tracks in the RG phase are by Charbonnel et al. (1996) and Schaller et al. (1992).

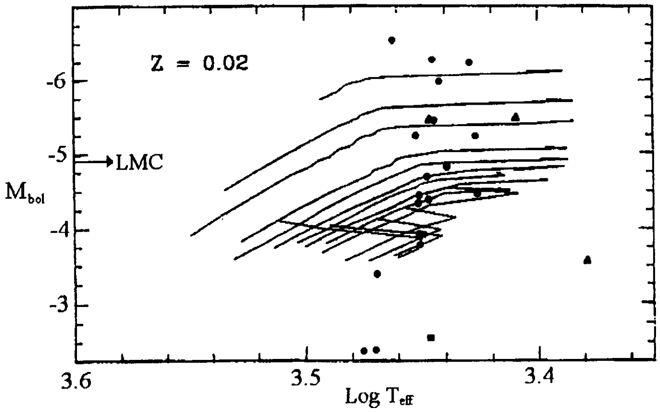

Fig. 2. Theoretical H-R diagram for N-stars. Triangles - large amplitude variables with $\Delta H_p > 1$ mag, dots - other stars, the square - V Ari. Tracks by Marigo et al. (1996) correspond to TP-AGB phase for initial masses 0.7 – 4 $M_\odot$.

As is evident from Fig. 1, N-type stars in the $M_V, (B-V)_0$ diagram occupy (with three exceptions) the interval $-4 < M_V < +1$ mag. with some concentration in the zone -1.5 – -3 mag. but the values of the normal color index $(B-V)_0$ lie in the interval 1.9 – 3.4 mag. Thus, Hipparcos results clearly confirm that the great range of observed scatter in the color index $B-V$ is intrinsic and not caused by different amounts of interstellar reddening, as sometimes has been assumed (e.g., Peery 1975, Johnson 1978).

A considerable stretch in the horizontal direction is a result of enhanced sensitivity of the color index $(B-V)_0$ to small temperature changes in a cool extended atmospheres; also various degree of violet depression play a definite role.

In Fig. 2 tracks calculated by Marigo et al. (1996) are reproduced and positions for N-type stars from Table 1 plotted. Tracks for initial mass in the interval $0.7 \leq M/M_\odot \leq 4$ start at first thermal pulse and end at the protoplanetary nebula stadium. It is evident that the majority of N-stars are located in a region which the evolutionary theory predicted for the advanced TP AGB phase with $C/O > 1$. Some outsiders are discussed below.

4.3. Stars with peculiar locations in the H-R diagram

There are some curious outsiders relative to the location of the bulk of the stars in Fig. 1. The stars having unusually low absolute magnitudes for carbon stars, $M_V > 1$ mag, should be noted. The carbon star nature for all of these stars is without doubt confirmed by many observers. The extreme example is the R-star HD97578 with $M_V = 7.6 \pm 1.0$ mag and a large (i.e., for a carbon star) parallax -31.2 ± 14.1 mas. The star is definitely lying below the subgiant branch for $M = 1M_\odot$ which starts at $M_V = 4.1$ mag. Thus, in principle, HD97578 must be considered as a carbon dwarf - a class known from searches among faint high latitude carbon stars (see e.g. Green et al. 1992) – although the great error of the parallax of the star cast doubts on the result.

Amongst N stars there are also some which have exceptionally low luminosity: HX Gem, RZ Peg and T Lyn, the last two being even Mira type variables. If we do not accept that the instability strip of long-period variability stretches to lower luminosities than traditionally accepted, the only way out of the discrepancy is to assume that Hipparcos parallaxes of these stars have a much greater error than that formally indicated in the catalogue. Indeed, these three stars are marked with the flag in Field H10 which indicates that the astrometric parameters refer to the photocenter of a double or multiple system. The value of the goodness-of-fit statistics of the astrometric solution, F2 > 2.3 for these three stars indicates that the Hipparcos solution is of low accuracy. Thus, the parallaxes of these stars might contain significant systematic errors.

From Hipparcos data, the star HIP 24548, identified with the carbon variable V431 Ori (BD 11^0755), also appears to be a carbon dwarf. However, it turns out that the identification is wrong and instead another nearby star BD 11^0754 has been observed.

At the opposite side – among unusually intrinsically bright carbon stars, as pointed out above, an exception is W CMa – a carbon star with initial mass possibly $> 10M_\odot$. Stellar evolutionary theory prohibits so massive an object to become a carbon star.

The possibility for W CMa to be a relict from former epochs of star formation in the association should also be mentioned. It has been claimed that in some associations and rich open clusters the seeming splitting of the main sequence in magnitude - color index diagrams is a manifestation of repeated star formation epochs (e.g. Wildey, 1964 for h-χ Per). For CMa OB1,however, photometric measurements (Claria, 1974) do not show any splitting of the main sequence. Further, in cases where several star generations are suspected the age interval between them is of the same order as the age of the association – $10^6 - 10^7$ yr whereas in the case under consideration it should be greater than $\sim 4{\cdot}10^8$ yr (age of carbon star with initial mass 4 $M_\odot$ (Schaller et al., 1992). It is doubtful that such a loose aggregate (about 500 $M_\odot$ on the area with angular diameter 4^0, Claria, 1974) may persist so long despite the tidal disruption by galactic differential rotation, and be capable of renewed star formation. Thus W CMa should be considered as the sole specimen bearing witness of repeated epochs of star formation in CMa OB1, a circumstance which casts doubt on the suggestion that W CMa belongs to a previous stellar generation.

The merger hypothesis which McClure (1997) proposed for the constitution of R-type stars, also is questionable in this case. Both stars must have $M \sim 5M_\odot$ – a limiting mass for carbon stars that is highly improbable. By merging of ordinary stars (though mixing is assured), it is difficult to get C/O>1, because only the evolutionary phase of central helium burning assures C/O>1 in the central region, but without detailed knowledge of the radial distribution of the abundances it is hard to say anything definite about the C/O value after merging.

So to eliminate the contradiction, one can accept that the star and probably its neighbours have had C/O>1 ab initio. Our knowledge about the C/O value in the galactic medium from where stars originate, and also in hot A-B stars is very scanty. In the last case, determination of C/O requires far ultraviolet spectroscopic observations with high dispersion and good models of stellar chromospheres – fields in which only first steps have been made. Another possibility is that the nebula in which the star is located is carbonaceous and contaminates the atmosphere of the star - a hypothesis which Maron (1978) put forward to explain the carbon star phenomenon. So whatever is its origin we must consider W CMa as cool supergiant in the phase of central helium burning with C/O>1.

Also WZ Cas – the next intrinsically brightest star in Table 1 – from a spectroscopic point of view is described as peculiar (Richer, 1971), incidentally having very strong NaI and LiI resonance doublets. According to Lambert et al. (1986) it has C/O=1.01 and therefore sometimes is classified as SC-type star.

Further multi-faceted investigation of such carbon stars in peculiar positions on H-R diagram are highly desirable.

4.4. Search for correlations among characteristics

It should be noted that we have not found a significant correlation between the absolute magnitudes M_b and effective temperatures or abundance ratios C/O and ^{12}C/^{13}C, as given by Lambert et al. (1986). From a theoretical point of view, such a correlation is also hard to expect for a sample consisting of stars with various initial masses and duration of evolution in the AGB stage. But there is an excellent correlation between M_K and M_{bol} with correlation coefficient $\varrho = 0.99$ – a reflection of an analogue correlation between m_K and m_{bol}. So, in order to find M_{bol} knowing the distance, it is sufficient to measure flux only in the K-band and to use the regression equation $M_{bol} = 2.23 + 0.92M_K$. The relation between M_{bol} and M_V is somewhat worse (ϱ=0.90) $M_{bol} = -3.38 + 0.84M_V$.

5. Conclusions

Briefly summarizing the results described above the following points could be noted.

1. A sample of about $\sim$ 40 bright carbon stars from the Hipparcos catalogue has been analysed. From trigonometric parallaxes and V magnitudes, distance moduli, absolute magnitudes, absorptions and normal color indices were found. For N-stars also absolute K and bolometric magnitudes have been calculated using data from infrared photometry.

2. Comparison of the derived absolute magnitudes with existing previous results showed a satisfactory agreement.

3. Comparing the mutual location of CH-, R-, and N-type stars in the observational ($M_V, (B-V)_0$) and theoretical (M_{bol}, T_{eff}) H-R diagrams, as well as their distribution regarding evolutionary tracks of stars with initial mass 1 – 4 $M_\odot$, it is evident that N-stars predominantly lie on tracks corresponding to the TP AGB phase (concentrating mostly on the highest, horizontal part of the tracks). R- and CH-stars are situated together on the red giant and subgiant branches. There is a clear dividing line between N-stars and R-, CH-stars at $(B-V)_0 \sim 1.6$ mag. On the observational H-R diagram, in contrast to R- and CH-stars (confined to a narrow $(B-V)_0$ interval), the N-type stars are stretched out over much wider interval of $(B-V)_0$ from $\sim$ 1.6 to 3.4 mag as a result of the strong dependence of color index on T_{eff} at $T_{eff} < 3000$ K, and varying degree of violet depression. In absolute magnitude, the interval of concentration for N-stars is -4.0 – +1.0 in M_V and -6.0 – -4.0 mag in M_{bol}.

4. Some of the stars analysed are lying below the subgiant branch for initial mass $1M_\odot$ – the smallest mass for stars which can reach the ABG in the lifetime of the Galaxy. Either these stars belong to the brightest dwarfs or their Hipparcos parallaxes have great systematic errors.

5. From three wide multiples, claimed to contain carbon stars, only in the case of W CMa (probable member of the CMa OB1 association), Hipparcos data confirms the physical link of components. As a member of a wide double star and an association, W CMa would have high luminosity (M_{bol}=-6.4) and mass greater than 10M$_\odot$, which is not characteristic for carbon stars and hardly explainable from a theoretical point of view. It is proposed that W CMa (and possibly neighbour A-B stars) could have C/O$>$1 ab initio.

6. The stars with peculiar locations in the H-R diagram (as W CMa, T Lyn, RZ Peg, HD 97578) deserve further, especially astrometric and spectroscopic, investigations.

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