Hipparcos Observations of Hydrogen-deficient Carbon Stars*

P. L. Cottrell[1] and W. A. Lawson[2]

[1]Mount John University Observatory, Department of Physics and Astronomy,
University of Canterbury, Christchurch, New Zealand
p.cottrell@phys.canterbury.ac.nz

[2]School of Physics, University College, UNSW, Australian Defence Force Academy,
Canberra, ACT 2600, Australia
w-lawson@adfa.oz.au

Abstract: Parallax measurements for 21 hydrogen-deficient carbon stars have been made by the *Hipparcos* satellite. These stars include most of the brighter R Coronae Borealis (RCB) variables, other cool hydrogen-deficient carbon (HdC) stars, and several higher-$T_{\rm eff}$ extreme helium (eHe) stars. Most of these stars have either negative or statistically insignificant parallaxes, indicating that they lie beyond the detection capability of *Hipparcos*. Although the distances to the galactic hydrogen-deficient carbon stars remain unknown, at least the *Hipparcos* observations do confirm that these objects must have high luminosity like the LMC RCB stars, for which $M_{\rm bol} = -4$ to -5. Based upon *Hipparcos* proper motions, we derive UVW velocities for the RCB and HdC stars, assuming $M_{\rm bol} = -3$ and -5. The UW-velocity dispersion of the RCB/HdC stars is similar to that already reported for the eHe stars, further supporting the idea that these groups of stars have predominantly bulge distributions. However, UW Cen may be a second example of a halo RCB star currently seen transitting the Galactic plane.

Keywords: stars: AGB and post-AGB — stars: carbon — stars: distances — stars: fundamental parameters — stars: kinematics

1 Introduction

The hydrogen-deficient carbon (HdC) stars consist of several groups of probably related objects with a combined known population in the Galaxy of about 100 stars. They are believed to be examples of post-AGB objects. Most exhibit a high degree of hydrogen depletion (up to factors of 10^5), although their metal abundances range from $0 \cdot 1$ solar to solar (Lambert & Rao 1994). The cooler hydrogen-deficient stars are generally separated into (1) the RCB stars, highly variable objects well known for their large-amplitude dust-formation events (declines) (Cottrell 1996; Clayton 1996) and (2) the HdC stars, which may be low-activity RCB stars on account of their lower pulsational activity (Lawson & Cottrell 1997) and evidence for limited mass loss (Walker 1986). The distinction between these two groups is often arbitrary, e.g. XX Cam has been variously classified as RCB or HdC, depending upon different characteristics of the star. The eHe stars are distinguished from the cool RCB/HdC stars in terms of $T_{\rm eff}$; the cool RCB/HdC stars have $T_{\rm eff} \approx 5000$–7500 K, whereas the eHe stars have $T_{\rm eff}$ exceeding $\sim$8000 K.

Spectroscopic analyses of these stars (Cottrell & Lambert 1982; Pollard, Cottrell & Lawson 1994; Lambert & Rao 1994) indicate that these are low-gravity objects ($\log g \approx 0$–1). The only distance estimates, and therefore observationally determined values for M_V or $M_{\rm bol}$, are for RCB stars in the LMC.

Three LMC RCB stars have been known since their discovery on the Harvard Observatory survey plates during the early decades of this century, but a larger population is currently emerging from the MACHO inventory of variable stars in the LMC. W Men and HV 12842 are F-type RCB stars, spectroscopically similar to the prototype Galactic RCB/HdC stars R CrB and RY Sgr (Pollard et al. 1994). Assuming a distance modulus to the LMC of $18 \cdot 7$ (Feast & Catchpole 1997), W Men and HV 12842 have M_V of $-4 \cdot 9$ and $-5 \cdot 0$ at maximum light, respectively. The cooler (K spectral type) LMC RCB star HV 5637 (Lawson et al. 1990; Glass, Lawson & Laney 1994) has $M_V = -4 \cdot 2$. Early results from the MACHO survey (Alcock et al. 1996; Clayton 1998) suggest a larger population (10–20 confirmed or probable RCB stars in fields examined to date) dominated by cooler, less-luminous stars with $M_V = -3$ to -4. After bolometric corrections are accounted for, these objects have mean luminosities

---

Table 1. *Hipparcos* data for 21 hydrogen-deficient carbon stars

Star	Type	Number (HIP)	α (J1991·25)	δ	π (mas)	μ_α (mas yr^{-1})	μ_δ	$\sigma\pi$ (mas)	$\sigma\mu_\alpha$ (mas yr^{-1})	$\sigma\mu_\delta$
XX Cam	HdC	019340	04 08 38·75	+53 21 39·4	−1·04	1·09	−3·46	0·90	0·74	0·71
SU Tau	RCB	027465	05 48 58·68	+19 04 36·4	3·32	3·57	1·17	5·24	6·16	3·28
BD +10°2179	eHe	052133	10 38 55·24	+10 03 48·5	0·49	−12·05	−3·18	1·61	1·83	1·55
UW Cen	RCB	062071	12 43 17·20	−54 31 40·7	1·27	−7·87	−12·64	2·81	3·26	3·89
Y Mus	RCB	063911	13 05 48·20	−65 30 46·6	8·02	−4·14	0·08	1·93	1·60	1·70
HD 124448	eHe	069619	14 14 58·64	−46 17 19·3	0·59	−7·54	1·01	1·75	1·20	1·30
S Aps	RCB	074179	15 09 24·55	−72 03 45·2	−0·89	−5·45	−0·76	1·56	1·37	1·68
HD 137613	HdC	075694	15 27 48·32	−25 10 10·1	−1·36	−1·84	−8·11	1·32	1·29	0·94
R CrB	RCB	077442	15 48 34·42	+28 09 24·4	0·54	−2·10	−11·52	0·72	0·37	0·49
HD 148839	HdC	081254	16 35 45·80	−67 07 36·7	1·47	−5·31	−3·20	1·11	0·72	0·88
HD 160641	eHe	086605	17 41 51·58	−17 53 48·5	−1·20	−1·64	1·57	2·14	2·28	1·55
RS Tel	RCB	089739	18 18 51·22	−46 32 53·4	3·00	−8·10	−5·49	2·98	3·52	2·27
HD 168476	eHe	090099	18 23 14·66	−56 37 44·1	−0·65	0·04	−9·08	1·30	1·22	0·87
HD 173409	HdC	092115	18 46 26·63	−31 20 32·1	1·95	−0·05	−4·45	1·57	1·97	1·19
V CrA	RCB	092207	18 47 32·31	−38 09 32·3	1·18	−6·03	−4·83	2·77	4·12	2·65
HD 175893	HdC	093181	18 58 47·29	−29 30 18·0	1·38	2·26	−3·36	1·42	1·71	1·05
SV Sge	RCB	093987	19 08 11·78	+17 37 41·2	0·52	0·82	6·65	3·56	3·05	2·92
RY Sgr	RCB	094730	19 16 32·76	−33 31 20·3	0·36	10·33	−0·41	1·12	1·15	0·62
HD 182040	HdC	095289	19 23 10·07	−10 42 11·6	0·00	7·11	1·72	0·98	0·80	0·50
V482 Cyg	RCB	098411	19 59 42·58	+33 59 28·0	−8·96	−4·84	−12·21	3·81	3·06	4·25
U Aqr	RCB	108876	22 03 19·70	−16 37 35·3	3·58	3·03	−2·53	2·55	3·19	1·40

at maximum light ranging from $M_{\rm bol} \approx -4$ to -5, with some probable scatter in $M_{\rm bol}$ for stars of similar spectral type.

Distances to the Galactic HdC stars would usefully contribute to a number of outstanding issues concerning these types of objects, e.g. whether the different metallicity environments of the LMC and the Galaxy result in different luminosities, support the possibility of a period–luminosity relationship as suggested in the LMC RCB stars, in conjunction with atmospheric models provide intrinsic colours and values for circumstellar reddening due to the presence of dust, and provide a direct measure of the extent of large circumstellar features known to surround some RCB stars.

2 *Hipparcos* Observations

The *Hipparcos* satellite was launched by the European Space Agency during 1989 August, with scientific observations made between 1989 November and 1993 March. More than 10^5 objects were observed for the *Hipparcos* Catalogue (ESA 1997), which has a mean astrometric precision of ∼1 milliarcsec (mas). Table 1 lists raw parallaxes and proper motions obtained for HdC stars observed as part of the *Hipparcos* catalogue (the catalogue reference number for each star is the HIP number in Table 1).

3 Discussion

Of the 21 HdC stars observed by *Hipparcos*, 20 have either null or negative parallaxes (7 stars) or less than $1·5\sigma$ positive parallaxes (13 stars). None of these 13 positive parallaxes are significant. Indeed, if bias effects such as the Lutz–Kelker statistical bias correction (Lutz & Kelker 1973; Koen 1992) are taken into account, these very weak positive values

are most likely overestimates of the true parallax for each star.

The RCB star Y Mus is apparently detected at $\pi = 8·02 \pm 1·93$ mas, i.e. a $4·2\sigma$ detection. Even a detection at this level is marginal for individual usefulness according to Koen (1992). However, even if the parallax was correct, the result is implausible for a RCB star. This parallax measurement corresponds to a distance of 126 ± 30 pc. At $m_V \approx 9·3$ and $(B–V)_{\rm o} \approx 0·6$ (Lawson et al. 1990; see Table 21), this would place the star at $M_V \approx 3·8$ and therefore near the main sequence. Y Mus is spectroscopically similar to Galactic RCB stars such as RY Sgr and R CrB, and the LMC RCB stars W Men and HV 12842. These are all low-gravity stars, with $\log g \approx 0$–1, which must imply an M_V of at least -3 or -4.

There is little likelihood that Y Mus has been misidentified with another star in the surrounding field. The star has no near neighbours of similar magnitude and the *Hipparcos* coordinate is accurate. The star was noted by ESA to be double or else affected by surrounding nebulosity (van Leeuwen, private communication). Either effect would render the parallax unreliable. Binarity would be surprising; none of the RCB stars or related objects are known to be in binary systems, which may be an indicator of their previous evolution. However, a number of RCB stars are known or suspected to be surrounded by extensive nebula (e.g. UW Cen; see Pollacco et al. 1991). But if either binarity or nebulosity is the correct explanation, Y Mus is unique in the class in showing such a highly distorted parallax.

We have attempted a mean parallax analysis for the 21 stars and derive $\overline{M_V} \sim -3$. The mean result is approximate to the expected value but is subject

Table 2. *Galactic distances, radial and space velocities, and theoretical parallaxes for cool hydrogen-deficient carbon stars*

Star	ℓ	b	M_{bol}	X	Y (kpc)	Z	RV	U	V (km s^{-1})	W	σU	σV	σW	π (mas)
RCB stars														
S Aps	313	−12	−5	3·9	−4·2	−1·2	−75	−144	−53	75	31	27	44	0·17
			−3	1·6	−1·7	−0·5		−87	11	39	12	11	17	0·43
U Aqr	39	−50	−5	6·6	5·4	−10·1	98	−44	−130	−227	160	84	120	0·076
			−3	2·6	2·2	−4·0		12	−30	−136	64	34	48	0·19
UW Cen	302	8	−5	2·9	−4·7	0·8	−16	−150	−132	−338	74	47	101	0·18
			−3	1·2	−1·9	0·3		−65	−45	−137	29	19	41	0·45
V CrA	358	−16	−5	7·4	−0·3	−2·1	−8	19	−248	133	38	107	138	0·13
			−3	2·9	−0·1	−0·8		3	−97	54	15	42	54	0·33
R CrB	45	51	−5	0·6	0·6	1·0	22	60	−42	18	3	2	2	0·77
			−3	0·2	0·2	0·4		30	−11	18	1	1	1	1·9
Y Mus	305	−3	−5	3·8	−5·5	−0·3	32	−90	−100	9	42	29	54	0·15
			−3	1·5	−2·2	−0·1		−25	−55	2	16	11	21	0·38
RY Sgr	5	−20	−5	1·6	0·1	−0·6	−21	−48	22	−68	3	6	8	0·59
			−3	0·6	0·0	−0·2		−30	8	−22	1	2	3	1·5
SU Tau	189	−4	−5	−3·8	−0·6	−0·3	37	−39	−21	64	10	77	101	0·26
			−3	−1·5	−0·2	−0·1		−38	−12	24	4	31	40	0·65
RS Tel	348	−14	−5	5·9	−1·3	−1·5	7	−11	−252	144	24	75	96	0·16
			−3	2·4	−0·5	−0·6		0	−100	57	10	30	38	0·40
HdC stars														
XX Cam	150	1	−5	−1·5	0·9	0·0	9	−22	−18	−15	3	5	6	0·56
			−3	−0·6	0·4	0·0		−13	−4	−6	1	2	2	1·4
HD 137613	342	25	−5	1·5	−0·5	0·8	71	62	−78	−9	6	9	8	0·56
			−3	0·6	−0·2	0·3		61	−43	15	2	4	3	1·4
HD 148839	322	−13	−5	2·3	−1·8	−0·7	−12	−56	−64	30	8	9	11	0·33
			−3	0·9	−0·7	−0·3		−28	−21	14	3	4	4	0·83
HD 173409	4	−13	−5	5·1	0·4	−1·2	−59	−60	−106	−30	11	33	45	0·19
			−3	2·0	0·1	−0·5		−58	−45	−4	5	13	18	0·48
HD 175893	7	−15	−5	3·4	0·4	−0·9	56	44	−32	−70	8	20	27	0·28
			−3	1·4	0·2	−0·4		50	−9	−37	3	8	11	0·70
HD 182040	27	−12	−5	1·2	0·6	−0·3	−35	−52	9	−30	2	3	5	0·71
			−3	0·5	0·3	−0·1		−39	−6	−7	1	1	2	1·8

to large error and therefore must be interpreted with caution, e.g. the sample size is small, the mean parallax is small ($\bar{\pi} = 0\cdot65$ mas), and there is uncertainty about the range of M_V in these types of stars.

Table 2 lists cool HdC stars observed by *Hipparcos* for which we have reliable estimates of m_{bol} (Lawson et al. 1990). In addition to their Galactic coordinates (ℓ, b) and heliocentric radial velocity (RV), we list Galactic distances (XYZ) with respect to the Sun and space velocities (UVW[1], with 1σ uncertainties) derived from the *Hipparcos* proper motions. The radial velocities for the RCB/HdC stars were mainly sourced from Lawson & Cottrell (1997), with the exception of SU Tau (Drilling & Hill 1986) and XX Cam (Herbig, unpublished). A $0\cdot5$ km s^{-1} uncertainty (1σ) in the radial velocity has been assumed for each star, which also contributes to the space motion uncertainty. For each star the distances and space velocities were calculated assuming either $M_{bol} = -5$ or -3, which should encompass the likely range of luminosity for these stars. We also derive a theoretical parallax π for each star at each luminosity.

[1] U is positive towards the Galactic centre, V is positive in the direction of Galactic rotation and W is positive towards the north Galactic pole.
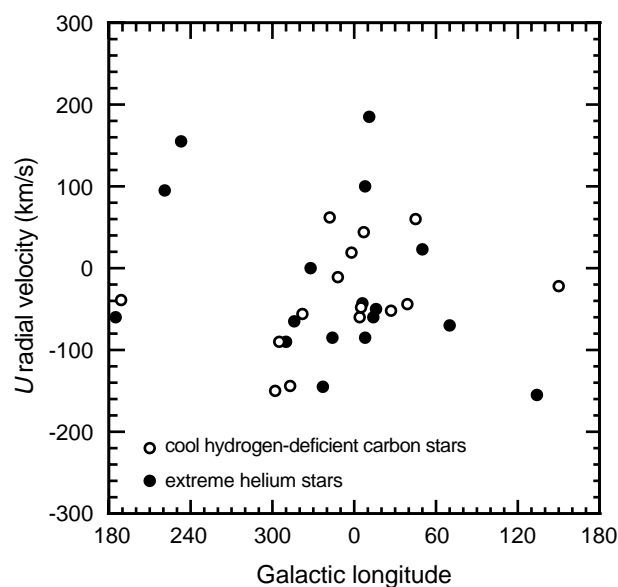
Figure 1—The U radial velocity (positive towards the Galactic centre) versus Galactic longitude for cool hydrogen-deficient carbon stars (open circles) and extreme helium stars (filled circles; data from Drilling 1986). The velocity and spatial distribution of these types of stars is discussed in the text.

We have not produced XYZ, UVW values for the four eHe stars listed in Table 1 due to the large variation in M_V across the eHe-star sequence

(e.g. Drilling 1986; see Figure 1) and the large and uncertain bolometric correction required for these high-temperature stars.

Some of the results in Table 2 are similar to those obtained previously, but the *Hipparcos*-derived *UVW* velocities are new. Drilling (1986) reported the distribution of some of the cooler RCB/HdC stars and most of the known eHe stars in the ℓ–b plane and the RV–ℓ plane; both planes showed a distribution indicative of a bulge population. Lawson et al. (1990) and Lawson & Cottrell (1990) showed a larger sample of cool HdC stars in the X–Y and X–Z planes, respectively, assuming $M_{\rm bol} = -5$. These show a known population skewed between $\ell = 300$ and $360°$, and avoiding much of the obscuration of the Galactic disk.

Assuming $M_{\rm bol} = -5$, the U-velocity dispersion of the RCB/HdC stars listed in Table 2 is similar to that reported for the eHe stars by Drilling (1986). Figure 1 shows these stars in the U-velocity/Galactic longitude plane. Considering only those stars that lie within $60°$ of the Galactic centre, the U-velocity dispersion of the RCB/HdC stars is $65\,{\rm km\,s^{-1}}$ (1σ), compared to $80\,{\rm km\,s^{-1}}$ (1σ) for the eHe stars. The small difference in the velocity dispersion may be accounted for by the eHe star sample in Figure 1 being a largely complete representation of known eHe stars, whereas only the brightest RCB/HdC stars are plotted, but it may simply be a function of the small sample sizes. The velocity and spatial distribution of both these types of stars is similar to that of other predominantly bulge populations, e.g. compact planetary nebulae (Drilling 1986).

With the exception of U Aqr and UW Cen, the W-velocity for the RCB/HdC stars shows a dispersion $(60\,{\rm km\,s^{-1}};\,1\sigma)$ similar to that of the U-velocity. U Aqr is a halo RCB star, with a Z-distance of -10 kpc. The high W-velocity of $-227\,{\rm km\,s^{-1}}$ is not unusual for a halo object. UW Cen is only 800 pc above the Galactic plane, unexceptional for the RCB/HdC stars listed in Table 2, yet has a W-velocity of $-338\,{\rm km\,s^{-1}}$. UW Cen may be another halo RCB star, seen transitting the Galactic plane. However, this velocity does have large uncertainty and the conclusion is sensitive to the adopted absolute magnitude.

The theoretical parallaxes for R CrB, RY Sgr, XX Cam, HD 137613 and HD 182040 should have been detected by *Hipparcos*, even if with considerable uncertainty, if these stars were $M_{\rm bol} = -3$. Yet none of these stars returned a statistically significant parallax.

Thus we must await the next generation of parallax/proper motion engines to reliably characterise the distances, proper motions and luminosities of these types of stars. At least the *Hipparcos* measurements support the results obtained for the LMC hydrogen-deficient stars; the Galactic RCB/HdC stars must also be high-luminosity objects.

Acknowledgments

Alcock, C., et al. 1996, ApJ, 470, 583
Clayton, G. C. 1996, PASP, 108, 225
Clayton, G. C. 1998, in ISO's View on Stellar Evolution, ed. R. Waters, in press
Cottrell, P. L. 1996, in Hydrogen Deficient Stars, ed. C. S. Jeffery & U. Heber, PASP Conf. Series, Vol. 96 (San Francisco: ASP), p. 13
Cottrell, P. L., & Lambert, D. L. 1982, ApJ, 441, 400
Drilling, J. S. 1986, in Hydrogen Deficient Stars and Related Objects, ed. K. Hunger et al. (Dordrecht: Reidel), p. 9
Drilling, J. S., & Hill, P. W. 1986, in Hydrogen Deficient Stars and Related Objects, ed. K. Hunger et al. (Dordrecht: Reidel), p. 499
ESA 1997, in The *Hipparcos* Catalogue, ESA SP-1200
Feast, M. W., & Catchpole, R. M. 1997, MNRAS, 286, L1
Glass, I. S., Lawson, W. A., & Laney, C. D. 1994, MNRAS, 270, 347
Koen, C. 1992, MNRAS, 256, 65
Lambert, D. L., & Rao, N. K. 1994, JA&A, 15, 47
Lawson, W. A., & Cottrell, P. L. 1990, in Confrontation between Stellar Pulsation and Evolution, ed. C. Cacciari & G. Clementini PASP Conf. Series, Vol. 11 (San Francisco: ASP), p. 566
Lawson, W. A., & Cottrell, P. L. 1997, MNRAS, 285, 266
Lawson, W. A., Cottrell, P. L., Kilmartin, P. M., & Gilmore, A. C. 1990, MNRAS, 247, 91
Lutz, T. E., & Kelker, D. H. 1973, PASP, 85, 573
Pollacco, D. L., Hill, P. W., Houziaux, L., & Manfroid, J. 1991, MNRAS, 248, 1P
Pollard, K. R., Cottrell, P. L., & Lawson, W. A. 1994, MNRAS, 268, 544
Walker, H. J. 1986, in Hydrogen Deficient Stars and Related Objects, ed. K. Hunger et al. (Dordrecht: Reidel), p. 409