The CH fraction of Carbon stars at high Galactic latitudes

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\textbf{ABSTRACT}

CH stars form a distinct class of objects with characteristic properties like iron deficiency, enrichment of carbon and overabundance in heavy elements. These properties can provide strong observational constraints for theoretical computation of nucleosynthesis at low-metallicity. An important question is the relative surface density of CH stars which can provide valuable inputs to our understanding on the role of low to intermediate-mass stars in the early Galactic chemical evolution. Spectroscopic characterization provides an effective way of identifying CH stars. The present analysis is aimed at a quantitative assessment of the fraction of CH stars in a sample of stars using a set of spectral classification criteria. The sample consists of ninety two objects selected from a collection of candidate Faint High Latitude Carbon stars from the Hamburg/ESO survey. Medium resolution ($\lambda/\delta\lambda \sim 1300$) spectra for these objects were obtained using OMR at VBO, Kavalur and HFOSC at HCT, IAO, Hanle, during 2007 - 2009 spanning a wavelength range 3800 - 6800 Å. Spectral analysis shows 36 of the 92 objects to be potential CH stars; combined with our earlier studies (Goswami 2005, Goswami et al. 2007) this implies $\sim 37\%$ (of 243) objects as the CH fraction. We present spectral descriptions of the newly identified CH star candidates. Estimated effective temperatures, $^{12}\text{C}/^{13}\text{C}$ isotopic ratios and their locations on the two colour J-H vs H-K plot are used to support their identification.

\textbf{Key words:} stars: CH stars - variable: carbon - stars: spectral characteristics - stars: AGB - stars: population II

1 INTRODUCTION

Carbon-rich stars ($[\text{C/Fe}] \geq +1.0$) comprise a significant fraction of metal-poor ($[\text{Fe/H}] \leq -2.0$) stars with estimates ranging from 14 ± 4\% (Cohen et al. 2005) to 21 ± 2\% (Lucatello et al. 2005); this fraction increases with decreasing metallicity (Rossi, Beers and Sneden 1999). A large fraction of carbon-enhanced metal-poor stars exhibit overabundances of neutron-capture elements relative to iron. Significant insight into the neutron-capture processes taking place in the early Galaxy can be derived from chemical composition studies of metal-poor carbon-stars (Norris et al. 1997a, 1997b, 2002; Bonifacio et al. 1998; Hill et al. 2000; Aoki et al. 2002a,b; Goswami et al. 2006, Aoki et al. 2007). However, formation mechanisms of these stars still remain poorly understood. The prime cause of the origin of C-N stars is believed to be the third dredge-up during the AGB evolutionary phase of low to intermediate-mass stars; the origin of C-R stars as well as SC-type stars still remains unclear (Izzard et al. 2007, Zijlstra 2004).

The population II CH stars, characterized by a strong G-band of CH and s-process elements play significant roles in probing the impact of s-process mechanisms in early Galactic chemical evolution. These stars are classified into two distinct types, the Late-type and the Early-type. This classification is based on their $^{12}\text{C}/^{13}\text{C}$ ratios; stars with a large value of $^{12}\text{C}/^{13}\text{C}$ ratio ($> 100$) belong to Late-type, and those with values of $^{12}\text{C}/^{13}\text{C}$ ratio ($\leq 10$) belong to Early-type. The two groups follow two distinct evolutionary paths. Late-type CH stars are further identified as intrinsic stars that generate s-process elements internally and the early-type CH stars as extrinsic stars; they receive the s-process elements via binary mass transfer. The chemical composition of early-type CH stars, if remains unaltered, would bear signatures of the nucleosynthesis processes operating in the low-metallicity AGB stars. Abundance analysis of such stars can provide observational constraints for theoretical modelling of s-process nucleosynthesis at very low-metallicity revealing the time of influence of this process on early Galactic Chemical Evolution (GCE).

Although new large-aperture telescopes has substantially enhanced the number of target stars for which high
spectral resolution data with high signal-to-noise ratio can be obtained, literature survey shows not many CH stars have been studied in detail so far. A major difficulty is in distinguishing these objects from other types of carbon stars. In particular, Population I C-R, C-N and dwarf carbon stars exhibit remarkably similar spectra with those of carbon giants. It is important to distinguish them from one another and understand the astrophysical implications of each individual class of stellar population. It is with this motivation we have undertaken to identify the CH stellar content as well as different types in a sample of stars presented by Christlieb et al. (2001b). Using low resolution spectral analysis we have classified the stars based on a set of spectral classification criteria. The present work led to the detection of 36 potential CH star candidates among ninety two objects. Combining this result with our previous studies we find $\sim 37\%$ (of 243) objects are potential CH star candidates. This set of objects would make important targets for detailed chemical composition studies based on high resolution spectroscopy.

Selection of the program stars is outlined in section 2. Observations and data reductions are described in section 3. In section 4 we briefly discuss the main features and spectral characteristics of C-stars. Description of the program stars spectra and results are drawn in section 5. Conclusions are presented in section 6.

2 SELECTION OF PROGRAM STARS

The program stars belong to the list of 403 Faint High Latitude Carbon (FHLC) stars presented by Christlieb et al. (2001b) from the database of Hamburg/ESO Survey (HES) described by Wisotzki et al. (2000). Hamburg/ESO Survey for carbon stars covers 6400 degree$^2$ limited by $\delta \leq +2.5^\circ$ and $|b| \geq 30^\circ$. The magnitude limit is $V \sim 16.5$. The wavelength range of the spectra is $3200$ to $5200$ Å at a resolution of $15$ Å at $H_\alpha$. Christlieb et al. found a total of 403 FHLC stars in this survey by application of an automated procedure to the digitized spectra.

The identification of these objects as FHLC stars was based on a measure of line indices - i.e. ratios of the mean photographic densities in the carbon molecular absorption features and the continuum band passes. The primary consideration is the presence of strong $C_2$ and CN molecular bands shortward of 5200 Å; CH bands were not considered.

At high galactic latitudes different kinds of carbon stars such as N-type carbon stars, dwarf carbon stars, CH-giants, warm C-R stars etc. are known to populate the region (Green et al. 1994). Goswami (2005) and Goswami et al. (2007) have conducted spectral classification of about 151 objects that belong to the FHLC stars sample offered by Christlieb et al. (2001b). These studies are enhanced by medium resolution spectroscopic analysis of an additional sample of ninety two objects observed during 2007 to 2009.

3 OBSERVATIONS AND DATA REDUCTION

Observations were carried out using the 2-m Himalayan Chandra Telescope (HCT) at the Indian Astronomical Observatory (IAO), Mt. Saranwati, Digpa-ratsa Ri, Hanle. The spectrograph used is the Himalayan Faint Object Spectrograph Camera (HFOSC). HFOSC is an optical imager cum a spectrograph for conducting low and medium resolution grism spectroscopy (http://www.iiap.res.in/centers/iao).

The grism and the camera combination used for observation provided a spectral resolution of $\sim 1330(\lambda/\delta \lambda)$; the observed bandpass ran from about 3800 to 6800 Å. All the objects listed in Table 1 and 2 are observed during 2007 - 2009. The $B_J$, $V$, $B-V$, $U-B$ colours in the tables are taken from Christlieb et al. (2001b). Determination of these values are described in Wisotzki et al. (2000) and Christlieb et al.(2001a). $B_J$ magnitudes are accurate to better than $\pm0.2$mag including zero point errors (Wisotzki et al. 2000). Spectra of HD 182040, HD 26, HD 5223, HD 209621, Z PSc, V460 Cyg and RV Set used for comparison were obtained during earlier observations using the same observational set up. A few spectra acquired using the OMR spectrograph at the cassegrain focus of the 2.3-m Vainu Bappu Telescope (VBT) at Kavalur, cover a wavelength range 4000 - 6100 Å at a resolution of $\sim 1000$. With a 600 line mm$^{-1}$ grating, we get a dispersion of 2.6 Å pixel$^{-1}$.

Observations of Th-Ar hollow cathode lamp taken immediately before and after the stellar exposures provide the wavelength calibration. The CCD data were reduced using the IRAF software spectroscopic reduction packages. For each object two spectra were taken and combined to increase the signal-to-noise ratio.

4 CHARACTERISTICS OF CARBON STARS AND SPECTRAL CLASSIFICATION

Spectral classification helps reducing the number of stars to be analyzed to a tractable number of prototype objects of different groups; each group may be correlated with one or more physical parameters such as luminosity and temperature. Abundance anomalies observed in carbon stars cannot be explained on the basis of observed temperature and luminosity of the stars; it is therefore difficult to devise a classification scheme for carbon stars based on only these two physical parameters. Morgan-Keenan system for carbon star classification (Keenan 1993) divided carbon stars into C-R, C-N and C-H sequence, with subclasses running to C-R6, C-N6 and C-H6 according to temperature criteria. In the old R-N system, CH stars that were classified as R-peculiar are put in a separate class in the new system. In the following we briefly discuss the main characteristics that place carbon stars into different groups. Detailed discussions on carbon stars are available in literature including Wallerstein and Knapp (1998) and references therein.

In contemporary stellar classification schemes assigning stars to ‘morphological groups’ is largely in practice. Carbon stars are primarily classified based on the strength of carbon molecular bands. The C-N stars are characterized by strong depression of light in the violet part of the spectrum. The cause of rapidly weakening continuum below about 4500Å is not fully established yet, but believed to be due to scattering by particulate matter. Oxygen-rich stars of similar effective temperatures do not show such weakening. C-N stars are also easily detected for their characteristic infrared colours. The majority of C-N stars show ratios of $^{12}\text{C} / ^{13}\text{C}$ in the range of 30 to 100 while in C-R stars this ratio ranges from...
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Table 1: HE stars with prominent C2 molecular bands observed during 2007 - 2009

| Star No. | RA (2000) | DEC (2000) | P | V | B-V | V-B | U-B | J | H | K | Drt of Obs |
|----------|-----------|------------|---|---|-----|-----|-----|---|---|---|-----------|
| HE 0008-1712 | 00 11 19.2 | -16.55 34.4 | 78.5866 | -76.2106 | 16.5 | 15.2 | 1.78 | 1.64 | 13.630 | 13.699 | 12.975 | 06.12.2009 |
| HE 0009-1824 | 00 12 18.5 | -18.07 55.5 | 75.8376 | -77.2654 | 16.5 | 15.7 | 1.09 | 0.58 | 14.080 | 13.724 | 13.665 | 11.09.2008 |
| HE 0037-0654 | 00 40 07.0 | -38.13 16.4 | 114.8685 | -99.3303 | 16.4 | 15.5 | 1.19 | 0.58 | 14.146 | 13.708 | 13.724 | 11.09.2008 |
| HE 0052-0530 | 00 55 00.0 | -17.27 02.0 | 125.3161 | -68.3057 | 16.5 | 15.0 | 1.95 | 1.74 | 12.952 | 12.241 | 12.086 | 12.09.2008 |
| HE 0100-1619 | 01 02 41.6 | -16.03 01.1 | 136.7651 | -78.6185 | 15.9 | 14.7 | 1.54 | 1.28 | 13.114 | 12.537 | 12.476 | 27.05.2008 |
| HE 0136-1831 | 01 39 01.8 | -18.16 43.0 | 176.4932 | -75.9517 | 16.5 | 15.6 | 1.72 | 1.43 | 14.216 | 13.679 | 13.532 | 12.09.2008 |
| HE 0721+0506 | 07 20 23.5 | -01 10 39.0 | 163.6904 | -54.5125 | 16.3 | 14.6 | 2.35 | 2.25 | 11.276 | 10.271 | 9.833 | 22.11.2008 |
| HE 1040+1041 | 10 42 35.6 | +00 10 24.0 | 427.6018 | -79.1517 | 16.7 | 15.1 | 1.51 | 1.34 | 12.412 | 11.731 | 11.522 | 18.01.2009 |
| HE 0228-0256 | 02 28 31.5 | -02 43 07.0 | 171.5942 | -55.8543 | 16.2 | 14.7 | 1.99 | 1.52 | 12.506 | 11.813 | 11.531 | 18.01.2009 |
| HE 0308-1031 | 03 10 27.1 | -06 13 41.1 | 201.1165 | -55.5582 | 16.5 | 15.2 | 1.19 | 1.02 | 9.628 | 9.475 | 9.331 | 21.11.2008 |
| HE 0420-1037 | 04 22 47.0 | -10 30 26.0 | 205.6454 | -37.7716 | 15.2 | 14.7 | 1.89 | 0.97 | 13.341 | 11.815 | 11.695 | 21.11.2008 |
| HE 0495-0813 | 04 48 27.0 | -08 27.4 | 245.0790 | 0.31497 | 16.2 | 15.3 | 1.22 | 1.11 | 13.531 | 13.026 | 12.903 | 08.04.2007 |
| HE 0594-0137 | 05 57 19.2 | +01 23 00.0 | 237.030 | 0.01800 | 16.6 | 15.7 | 1.18 | 0.32 | 14.022 | 12.912 | 12.152 | 21.11.2008 |
| HE 0611-0942 | 06 10 25.4 | -09 57 54.0 | 235.7699 | -89.5285 | 15.4 | 14.2 | 1.65 | 1.76 | 11.209 | 10.432 | 10.125 | 27.05.2008 |
| HE 0710-1048 | 07 11 26.6 | -10 48 51.0 | 246.4582 | -90.5185 | 15.4 | 14.2 | 1.65 | 1.76 | 11.209 | 10.432 | 10.125 | 10.03.2008 |
| HE 0719-2334 | 07 19 24.4 | -23 34 51.2 | 253.9281 | -90.0595 | 15.4 | 14.2 | 1.65 | 1.76 | 11.209 | 10.432 | 10.125 | 10.03.2008 |
| HE 0720-0242 | 07 20 13.0 | -02 42 30.0 | 252.7778 | -90.1042 | 15.4 | 14.2 | 1.65 | 1.76 | 11.209 | 10.432 | 10.125 | 10.03.2008 |
| HE 0745-0138 | 07 45 11.8 | -01 24 58.0 | 255.6457 | -90.8263 | 15.4 | 14.2 | 1.65 | 1.76 | 11.209 | 10.432 | 10.125 | 10.03.2008 |

From Christlieb et al. (2001a).
dial velocity survey CH stars are known to be binaries. According to the models of McClure (1983, 1984) and McClure & Woodworth (1990) the CH binaries have orbital characteristics consistent with the presence of a white dwarf companion. Early type CH stars are believed to have conserved the products of the carbon rich primary received through mass transfer and survived until the present in the Galactic halo. CH stars are not a homogeneous group of stars. They consist of two populations, the most metal-poor ones have a spherical distribution and the ones slightly richer in metals are characterised by a flattened ellipsoidal distribution (Zinn 1985). The ratio of the local density of CH stars was found to be ~30% of metal-poor giants (Hartwig & Cowley 1985).

Many C-R stars also show a quite strong G band in their spectra. Hence, based only on the strength of the G-band of CH it is not possible to make a distinction between CH and C-R stars. In such cases the secondary Pbranch head near 4342 Å serves as a more useful indicator. This is a well-defined feature in CH star spectra in contrast to its appearance in C-R star spectra (refer Fig. 2, 3 of Goswami 2005). Another important diagnostic feature is Ca I at 4226 Å which in case of CH stars is weakened by the overlying CH band systems. In C-R star's spectra this feature is quite strong; usually the line depth is deeper than the depth of the
CN molecular band around 4215 Å. These spectral characteristics allow for an identification of the CH and C-R stars even at low resolution.

Abundances of neutron-capture elements can also be used as an useful indicator of spectral type. The abundances of s-process elements are nearly solar in C-R stars (Dominy 1984); whereas the CH stars show significantly enhanced abundances of the s-process elements relative to iron (Lambert et al. 1986, Green and Margon 1994). Although, the C-R as well as CH stars have warmer temperatures than those of C-N stars and blue/violet light is accessible to observation and atmospheric analysis, at low dispersion the narrow lines are difficult to estimate and elemental abundances can not be determined. At low dispersion, therefore, the ‘abundance criteria’ can not be used to distinguish the C-R stars from the CH stars. Although the CH and C-R stars have similar range of temperatures, the distribution of CH stars place most of them in the Galactic halo. The large radial velocities, typically $\sim 200$ km s$^{-1}$ of the CH stars are indicative of their being halo objects (McClure 1983, 1984).

C-J stars spectra are characterized by strong Merrill-Sanford (M-S) bands ascribed to SiC$_2$ that appear in the wavelength region 4000 - 4977 Å. The SiC$_2$ being a triatomic molecule, M-S bands are expected to be the strongest in the coolest stars. SiC$_2$ and C$_2$ have similar molecular structures and in many C stars C$_2$ molecule is believed to be the cause of ultraviolet depression (Lambert et al. 1986). These bands are absent in the spectra of known CH stars. A few warmer C-N stars are known to exhibit the presence of M-S bands in their spectra. Strength of M-S bands are known to show a distinct correlation with carbon isotopic ratios; i.e., stars with higher $^{13}$C/$^{12}$C ratios show weaker M-S bands. WZ Cas, V Aqgl & U Cam are a few exceptions that have low $^{13}$C and strong M-S bands (Barnbaum et al. 1996). Strong C-molecular bands but a weak CH band characterize the class of hydrogen deficient carbon stars.

We have classified the program stars guided by the above spectral characteristics. In the present sample of ninety two stars the spectra of twenty two objects are found to not exhibit molecular bands of C$_2$. These objects are listed in Table 2. Among the seventy stars that exhibit strong carbon molecular bands (Table 1) thirty six of them are found to show spectral characteristics of CH stars. These potential CH star candidates are listed in Table 3. In the following we discuss the spectral characteristics of the individual objects.

5 RESULTS AND DISCUSSIONS

The spectra of the objects are primarily examined in terms of the following spectral characteristics.
1. The strength (band depth) of the CH band around 4300 Å.
2. Prominence of the secondary P-branch head near 4342 Å.
3. Strength/weakness of the Ca I feature at 4226 Å.
4. Isotopic band depths of C$_2$ and CN, in particular the Swan bands of $^{12}$C$^{13}$C and $^{13}$C$^{13}$C near 4700 Å.
5. Strengths of the other C$_2$ bands in the 6000 - 6200 Å region.
6. The $^{13}$CN band near 6360 Å and the other CN bands across the wavelength range.
7. Presence/absence of the Merrill-Sanford bands around 4900 - 4977 Å region.
8. Strength of the Ba II features at 4554 Å and 6496 Å.

The membership of a star in a particular group is established from a differential analysis of the program stars spectra with the spectra of the comparison stars. Spectra of carbon stars available in the low resolution spectral atlas of carbon stars of Barnbaum et al. (1996) are also consulted. In Figure 1 we reproduce the spectra of the comparison stars in the wavelength region 4000 - 6800 Å; in figure 2 we show one example of HE stars spectra from the present sample corresponding to each comparison star’s spectrum in figure 1.

5.1 Location of the candidate CH stars on (J-H) vs (H-K) plot

We have used JHK photometry as supplementary diagnostics for stellar classification. Figure 3 shows the locations of the candidate CH stars listed in Table 3 on the (J-H) vs (H-K) plot. 2MASS JHK measurements of the stars are available on-line at [http://www.ipac.caltech.edu/](http://www.ipac.caltech.edu/). The thick box on the lower left represents the location of CH stars and the thin box on the upper right represents the location of C-N stars (Totten et al. 2000). Except two lying outside (shown with open squares in figure 3), the locations of the candidate CH stars (shown with open circles) are well within the CH box. This supports their identification with the class of CH stars. Location of the comparison CH stars HD 26, HD 5223 and HD 209621, C-R star RV Sct, C-N stars V460 Cyg and Z PSc, are shown by solid squares on the (J-H) vs (H-K) plot. As described in the next section, we have also used 2MASS JHK photometry to determine the effective temperatures of the objects.

5.2 Effective temperatures of the program stars

Semiempirical temperature calibrations offered by Alonso et al. (1994, 1996, 1998) are used to derive preliminary temperature estimates of the program stars. These authors used the infrared flux method to measure temperatures for a large number of lower main sequence stars and subgiants to derive the calibrations. The calibrations relate $T_{\text{eff}}$ with Stromgren indices as well as [Fe/H] and colours (V-B), (V-K), (J-H) and (J-K). The calibrations hold within a temperature and metallicity range $4000 \leq T_{\text{eff}} \leq 7000$ K and $-2.5 \leq [\text{Fe/H}] \leq 0$. The estimated uncertainty in $T_{\text{eff}}$ arising from different sources is $\sim 90$ K (Alonso et al. 1996). Alonso et al. derived the $T_{\text{eff}}$ scales using photometric data measured on TCS system; 2MASS JHK photometric data are therefore converted to the TCS system using the conversion relations of Ramirez and Melendez (2004). Estimation of $T_{\text{eff}}$ from (J-H) & (V-K) temperature relations involve a metallicity term; (J-K) calibration relation is independent of metallicity. We have estimated the effective temperatures using adopted metallicities shown in parenthesis in Table 4. (B-V) calibration, normally used in case of normal stars is not considered as in the case of carbon stars the colour B-V depends on the chemical composition and metallicity
in addition to $T_{\text{eff}}$. B-V colour often gives a much lower value than the actual surface temperature of the star due to the effect of CH molecular absorption in the B band. We have assumed that the effects of reddening on the measured colours are negligible.

5.3 Isotopic ratio $^{12}\text{C}/^{13}\text{C}$ from molecular band depths

Carbon isotopic ratios $^{12}\text{C}/^{13}\text{C}$, widely used as mixing diagnostics provide an important probe of stellar evolution. These ratios measured on low resolution spectra do not give accurate results but provide a fair indication of evolutionary states of the objects.

We have estimated these ratios, whenever possible, using the molecular band depths of $(1,0) \ ^{12}\text{C}^{12}\text{C} \lambda 4737$ and $(1,0) \ ^{12}\text{C}^{13}\text{C} \lambda 4744$. For a majority of the candidate CH stars, the ratios $^{12}\text{C}/^{13}\text{C}$ are found to be $\leq 10$. These ratios for HD 26, HD 5223 and HD 209621 are respectively 5.9, 6.1 and 8.8 (Goswami 2005).

Our estimated ratios of $^{12}\text{C}/^{13}\text{C}$ indicate that most of the candidate CH stars belong to the 'early-type' category. The low carbon isotope ratios imply that, in a binary system, the material transferred from the now unseen companion has been mixed into the CN burning region of the CH stars or constitute a minor fraction of the envelope mass of the CH stars. Low isotopic ratios are typical of stars on their first ascent of the giant branch. The $^{12}\text{C}/^{13}\text{C}$ ratios and the total carbon abundances decrease due to the convection which dredges up the products of internal CNO cycle to stellar atmosphere as ascending RGB. If it reaches AGB stage, fresh $^{12}\text{C}$ may be supplied from the internal He burning layer to stellar surface leading to an increase of $^{12}\text{C}/^{13}\text{C}$ ratios again.

5.4 Spectral characteristics of the candidate CH stars

HE 0420-1037, 1102-2142, 1142-2601, 1146-0151, 1210-2636, 1253-1859, 1447+0102. The spectra of these objects resemble closely the spectrum of HD 26. HD 26 is a known classical CH star with effective temperature 5170 K and log $g = 2.2$ (Vantures 1992b). The temperatures
Figure 2. An example of each of the HE stars corresponding to the comparison stars presented in Figure 1, in the top to bottom sequence, in the wavelength region 3860 - 6800 Å. The locations of the prominent features seen in the spectra are marked on the figure.

of these objects as measured using JHK photometric data range from 4200 to 5000 K. The locations of these objects are well within the CH box in figure 3. In figure 4, we show as an example, a comparison of the spectra of three objects HE 0420-1037, HE 1142-2601 and HE 1146-0151 with the spectrum of HD 26. With marginal differences in the strengths of the molecular features, the spectra of these three objects show more or less a good match with their counterparts in HD 26. The CN band around 4215 Å and the C$_2$ band around 5165 Å in the spectra of HE 0420-1037 and HE 1146-0151 are marginally stronger; the Na I D feature also appears stronger. The features due to Ca K and H appear with similar strengths. In the spectrum of HE 1142-2601, the CN band depth around 4215 Å and Ca II K and H line depths are deeper than their counterparts in HD 26. The Ca I line at 4226 Å is detected with line depth weaker than the band depth around 4215 Å. In HD 26, the Ca I 4226 Å feature is not detected. The object HE 1253-1859 also have very similar spectrum with that of HD 26. The CN band around 4215 Å and carbon isotopic band around 4730 Å are stronger, but the CH band, Ca II K and H features are of similar strengths. The molecular bands around 5165 Å and 5635 Å show an exact match. The lines due to Na I D, Ba II at 6496 Å and H$_\alpha$ are seen equally strongly as in HD 26. The Ca I feature at 4226 Å could not be detected and the secondary P-branch head around 4342 Å seems to be marginally weaker. In the spectrum of HE 1102-2142 the molecular C$_2$ bands around 4735, 5165 and 5635 Å are slightly deeper than those in HD 26. The CN band around 4215 Å and the CH band around 4310 Å also appear marginally stronger in the spectrum of HE 1102-2142. The H$_\alpha$ feature and the Ba II line at 6496 Å are marginally weaker; the feature due to Na I D appears with similar strength as in HD 26. H$_\beta$ at 4856 Å is clearly seen. The Ca I line at 4226 Å is weakly detected. In the spectrum of HE 1210-2636, the CN band around 4215 Å and the secondary P-branch head around 4342 Å appear slightly stronger than in HD 26. The C$_2$ molecular band around 5165 Å is also slightly weaker. The carbon isotopic band around 4733 Å is marginally detectable. Ca I line at 4226 Å could not be detected. Features due to Ca II K and H and H$_\alpha$ are clearly detected. In the spectrum
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Figure 3. A two colour J-H versus H-K diagram of the candidate CH stars. The thick box on the lower left represents the location of CH stars and the thin box on the upper right represents the location of C-N stars (Totten et al. 2000). Majority of the candidate CH stars listed in Table 3 (represented by open circles) fall well within the CH box. The positions of the two outliers are shown with open squares. C-N stars found in our sample are represented by solid triangles. The location of the comparison stars are labeled and marked with solid squares. Location of the three dwarf carbon stars are indicated by open triangles.

Figure 3. A two colour J-H versus H-K diagram of the candidate CH stars. The thick box on the lower left represents the location of CH stars and the thin box on the upper right represents the location of C-N stars (Totten et al. 2000). Majority of the candidate CH stars listed in Table 3 (represented by open circles) fall well within the CH box. The positions of the two outliers are shown with open squares. C-N stars found in our sample are represented by solid triangles. The location of the comparison stars are labeled and marked with solid squares. Location of the three dwarf carbon stars are indicated by open triangles.

of HE 1447+0102, the CN band around 4215 Å is almost absent. Strong well defined features due to Ca II K and H are seen. Molecular bands around 4733, 5165, and 5635 Å are distinctly seen to be stronger than their counterparts in HD 26. In the redward of 5700 Å no molecular bands are detected. We assign these objects to the CH group.

HE 0136-1831, 0308-1612, 1027-2501, 1051-0112, 1119-1933, 1120-2122, 1123-2031, 1145-1319, 1205-2539, 1331-2558, 1404-0846, 1425-2052, 1525-0516, 2114-0603, 2211-0605, 2228-0137, 2246-1312. The spectra of these objects resemble closely the spectrum of HD 209621, a classical CH star with effective temperature ~ 4400 K (Tsuji et al. 1991). The effective temperatures estimated for this set of objects using JHK photometry range from 3948 K (HE 2114-0603) to 4675 K (HE 1119-1933). Their locations on the J-H vs H-K plot are well within the CH box in figure 3. Three examples, HE 0136-1831, HE 1027-2501 and HE 2228-0137 from this set are shown in figure 5 together with the spectrum of HD 209621. In the spectrum of HE 0136-1831, the CN band around 4215 Å is marginally weaker and the carbon molecular bands around 4733 and 5635 Å are marginally stronger than those in HD 209621. All other features show a good match. The spectrum of HE 1027-2501 also shows a close match with the spectrum of HD 209621. Except for the molecular bands around 4733, 5165 and 5635 Å that appear marginally weaker in the spectrum of HE 2228-0137 the spectrum of this object bears a close resemblance with the spectrum of HD 209621. The spectrum of HE 0308-1612 shows weaker molecular bands around 5165 Å and 5635 Å. The CN band around 4215 Å and the carbon isotopic band around 4730 Å are of similar strengths. The CH band around 4300 Å and Ca II K and H features are of similar depths. The lines due to Na I D, Ba II at 6496 Å and Hα are clearly noticed. The Ca I feature at 4226 Å could not
be detected. The spectrum of HE 1051-0112 shows a weaker CN band around 4215 Å. The G-band of CH appears with almost the same strength as in HD 209621. The secondary P-branch head around 4342 Å and the bands around 4730 and 5635 Å are relatively stronger. Features due to Ca II K and H are barely detectable in the spectrum of this object. The molecular band around 5165 Å shows an exact match with its counterpart in HD 209621. The features due to Hα and Na I D are detected distinctly; the Ba II feature at 6496 Å is marginally detected.

In the spectrum of HE 1119-1933, Ca II K and H appear marginally stronger. The molecular band around 5365 Å appears marginally weaker than in HD 209621. The spectra of HE 1120-2122 and HE 1123-2031 are very similar, both exhibit a weaker CN band around 4215 Å. All other features show a good match with their counterparts in the spectrum of HD 209621. Ca II K and H appear with almost the same strength in the spectrum of HE 1120-2122 as in HD 209621. Ca I line at 4226 Å is not detectable. The spectra of HE 1123-2031, HE 1145-1319, HE 1205-2539, HE 1331-2558 are noisy shortward of 4100 Å and the lines due to Ca II K and H could not be clearly detected. Ca I line at 4226 Å is not detectable in these spectra. Features due to Na I D, Hα, and Ba II at 6496 Å are detected. In the spectrum of HE 1145-1319, C2 molecular bands around 5635 and 4733 Å are marginally deeper than those in HD 209621. The features redward of 4200 Å in the spectrum of HE 1205-2539 show a good match with those in HD 209621. The molecular features in the spectrum of HE 1331-2558 are also of similar strengths with those in HD 209621. Except for the G-band of CH, all other molecular features are weaker in the spectrum of HE 1404-0846. The features due to Ca II K and H are marginally stronger. The spectrum of HE 1404-0846 is noisy at the blue end.

In the spectrum of HE 1425-2052 the G-band of CH and the C2 band around 5635 Å are mildly stronger. The rest of the features show a close match with their counterparts in HD 209621. The Ba II feature at 6496 Å appears with equal intensity as that of Hα feature. The feature due to Na I D is clearly detected. In the spectrum of HE 1525-0516, Hα and Na I D features are detected with almost equal strength as in HD 209621. The spectrum of

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**Figure 4.** A comparison of the spectra of three HE stars in the wavelength region 3870 - 5400 Å with the spectrum of the comparison star HD 26. Prominent features noticed in the spectra are marked on the figure.
HE 2114-0603 shows a remarkably close match with the features in HD 209621 including those longward of 5700 Å. However the features due to Ca II K and H that are seen very distinctly in the spectrum of HD 209621 could not be detected in the spectrum of HE 2114-0603; the spectrum is noisy blueward of 4000 Å. In the spectrum of HE 2211-0605 the molecular features are weaker than their counterparts in HD 209621 but stronger than those in HD 26. The CH band matches exactly with the one in HD 209621. Ca II K and H appear with almost equal strengths as in HD 209621. The spectrum of HE 2246-1312 shows a weaker molecular band around CN 4215 Å. Other molecular bands appear with almost equal strengths as their counterparts in HD 209621. The spectrum blueward of 4100 Å is noisy and Ca II K and H features could not be detected as well defined features. The spectrum obtained in september 2008 has a better signal.

HE 0008-1712, 0052-0543, 0100-1619, 0225-0546, 1045-1434, 1110-0153, 1157-1434, 1228-0417, 1405-0346, 1410-0125, 1431-0755, 1440-1511. The spectra of these objects closely resemble the spectrum of HD 5223, a well-known classical CH star with effective temperature $\sim$ 4500 K, log $g$ = 1.0 and metallicity $[\text{Fe/H}] = -2.06$ (Goswami et al. 2006). The effective temperatures of these objects derived from J-K colour range from about 3924 K (HE 0052-0543) to 4795 K (HE 1228-0417). Except for the two outliers HE 1045-1434 and HE 1228-0417 (represented with open squares) the locations of this set of objects are well within the CH box in figure 3.

A comparison of the spectra of HE 0008-1712, HE 0100-1619 and HE 1405-0346 with the spectrum of HD 5223 is shown in figure 6. The Ca I line at 4226 Å is not detectable in any of these spectra. The CH band as well as other molecular bands show a very good match. The features due to Ca II K and H are seen with equal strength as in HD 5223. The CN band around 4215 Å in HE 0100-1619 is slightly deeper. The bands longward of 5635 Å are also marginally deeper. This object HE 0100-1619 is also mentioned as a CH star in Totten et al. (2000). Heliocentric radial velocity of HE 0100-1619 as reported by Bothun et al. (1991) is $-142$ km s$^{-1}$.

The spectra of HE 0052-0543 and HE 1110-0153...
show stronger molecular bands than their counterparts in HD 5223. In the spectrum of HE 0225-0546 the molecular bands are marginally stronger than in HD 5223. The molecular features above 5700 Å seen in these two spectra are barely noticed in the spectrum of HD 5223. The spectrum of HE 1157-1434 also show a good match with the spectrum of HD 5223 except for the molecular band around 5635 Å which is distinctly weaker in its spectrum. The molecular features redward of 5700 Å are also noticed weakly in the spectrum of this object. The spectrum of HE 1405-0346 shows a stronger CN band around 4215 Å as well as a stronger carbon molecular band around 5635 Å. The secondary P-branch head near 4342 Å is also stronger than its counterpart in HD 5223. Other molecular bands around 4733 and 5165 Å show a good match. Ca II K and H are seen as strongly as in HD 5223. The effective temperature of the object from J-K colour is 4391 K, slightly lower than the effective temperature of HD 5223. In the spectrum of HE 1410-0125 the molecular features are slightly shallower than their counterparts in HD 5223. The CH band depth is however of similar strength. The feature at Ca I 4226 Å is absent; the features due to Ca II K and H are of similar strengths. The CN band around 4215 Å matches well with the CN feature in HD 5223. The radial velocity of this object as quoted by Frebel et al. (2006) is +80 Km s\(^{-1}\). The effective temperature estimated using (J-K) calibration returns a value 4378 K for this object.

The spectrum of HE 1431-0755 is noisy blueward of 4000 Å; the features of Ca II K and H could not be detected. The CH band around 4310 Å and the CN band around 4215 Å appear slightly stronger than their counterparts in HD 5223. Other C\(_2\) molecular bands present in the spectrum are narrower than their counterparts in HD 5223. The spectrum redward of 5700 Å shows molecular features that are barely noticed in the spectrum of HD 5223. The spectrum of HE 1440-1511 shows molecular bands with almost equal depths with those in HD 5223. Ca II K and H features are however stronger than their counterparts in HD 5223. The spectrum shows a distinctly stronger feature due to Na I D. Features of H\(_\alpha\) and Ba II at 6496 Å are of equal strengths. The spectrum redward of 5700 Å shows a good match.

In the spectrum of HE 1228-0417 the Ba II feature at
6496 Å and H$_\alpha$ are seen with equal strengths as in HD 5223. The part of the spectrum redward of 5700 Å shows a very good match. The Ca I line at 4226 Å is not detected. The feature due to Na I D is clearly detected. Other carbon molecular features around 4730, 5165, and 5635 Å appear marginally weaker than their counterparts in HD 5223. The G-band of CH appears with almost equal strength but marginally weaker than its counterpart in HD 5223. The effective temperature of the object estimated using J-K colour calibration is 4795 K, higher than the effective temperature of HD 5223 ($\sim 4500$ K) (Goswami et al. 2006). The location of this object outside the CH box is not obvious from its low resolution spectra.

**IE 0009-1824, 1116-1628, 1358-2508.** The spectra of these objects are illustrated in figure 7. These three objects are known dwarf carbon stars. The effective temperatures of HE 0009-1824, HE 1116-1628, HE 1358-2508 as estimated from (J-K) calibration are respectively 5530 K, 4224 K and 3623 K. As expected, the molecular band depths are the strongest in HE 1358-2508, the coolest of the three objects; and weakest in HE 0009-1824. In the spectrum of HE 0009-1824 the CN band around 4215 Å is completely missing. The features due to Ca II K and H as well as the CN band near 3880 Å are detected. The G-band of CH is strong but not as strong as it appears in CH stars. The secondary P-branch head near 4342 Å is seen distinctly. Apart from the absence of the CN band around 4215 Å the spectrum of this object looks somewhat similar to the spectrum of HD 209621. The distance of this object as reported by Mauron et al. (2007) is 300 pc.

The spectra of HE 1116-1628 and HE 1358-2508 show characteristics of C-R star RV Sct with marginal differences in the molecular band depths. In the spectrum of HE 1358-2508, the CH band is marginally stronger than in RV Sct. The C$_2$ molecular bands are stronger in the spectrum of this object. The CN band around 4215Å is clearly detected. Ratnatunga (1983) first proposed this object HE 1116-1628 to be a dwarf carbon star. This object is also present in the list of dwarf carbon stars of Lowrance et al. (2003). Mauron et al. (2007) reported the proper motions in µ$^{\alpha}$ and µ$^{\delta}$ and their respective 1σ errors in mas yr$^{-1}$ as $-23.5 \pm 6.7$ and $+29.8 \pm 4.6$. The distances of HE 1116-1628 and HE 1358-2508 as reported by Mauron et al. (2007) are 170 pc and 270 pc respectively. Totten and Irwin (1998) reported a radial velocity of $-69$ km s$^{-1}$ for the object HE 1116-1628. All the three objects have total proper motion $\mu \geq 30$ mas yr$^{-1}$ (Mauron et al. 2007).

The locations of the three dwarf carbon stars are indicated by open triangles in figure 3. Location of HE 0009-1824 is on the left below the CH box, the location of HE 1358-2508 is on the right edge of the CH box and the location of HE 1116-1628 is found to be well inside the CH box. Dwarf carbon stars have anomalous infrared colours (Green et al. 1992 and Westerlund et al. 1995). In the conventional two colour JHK diagram the locus of dwarf-carbon-stars colours is away from the normal carbon-star locus. The locus defined by dwarf carbon stars is bounded by (J-H) $\leq 0.75$ and (H-K) $\geq 0.25$ (Westerlund et al. 1995). This condition is satisfied by HE 1358-2508; however HE 0009-1824, and HE 1116-1628 both have (H-K) colours less than the lower limit of 0.25 mag set for dwarf carbon stars.

**Candidate C-N stars: HE 0217+0056, 0228-0256, 1019-1136, 1344-0411, 1429-1411, 1442-0058, 2213-0017, 2225-1401.** The spectra of these objects show a close resemblance with the spectrum of the C-N star Z Psc with similar strengths of CN and C$_2$ molecular bands across the wavelength regions. In figure 3, the objects HE 0217+0056, HE 1019-1136, HE 1344-0411, HE 1429-1411, HE 1442-0058 and HE 2213-0017 represented by solid triangles lie well within the CH box. The spectra have low flux below about 4400 Å. The spectrum of HE 1429-1411 is similar to that of Z Psc’s spectrum, except that the CN band around 4215 Å is marginally weaker in this star. The CH band is weakly detected in the spectrum of HE 1116-1628. The molecular bands near 4735, 5135 and 5635 Å are noticed distinctly. The feature due to Na I D is strongly detectable. The Ba II line at 6496 Å is detectable but the H$_\alpha$ feature could not be detected. HE 1127-0604 has low flux below about 4200 Å. The CH band and C$_2$ molecular bands around 4735, 5165, 5635 Å are detected. All the features in the spectrum are weaker than their counterparts in Z Psc. While features of Ca II K and H are detected, the CN band around 4215 Å is not clearly seen. The spectrum of HE 2225-1401 has low flux below about 4700 Å. The strong C$_2$ molecular bands around 5165, 5635 Å appear stronger than their counterparts in Z Psc. The spectrum of HE 2225-1401 although have spectral characteristics of C-N stars, its location in figure 3 is not within the CH box. The spectra of the objects HE 2213-0017, HE 1442-0058, HE 1344-0411 compare closest to the spectrum of C-N star V460 Cyg as illustrated in figure 8.

The objects HE 0217+0056, HE 1019-1136, HE 1442-0058, HE 2213-0017 and HE 2225-1401 are also mentioned as N-type stars in the APM survey of cool carbon stars in the Galactic halo (Totten & Irwin 1998). Totten et al. (2000) have provided proper motion measurements for these objects. The distances measured by these authors assuming an average $M_R = -3.5$ for these objects are respectively 24, 16, 43, 29 and 24 kpc. Heliocentric radial velocities estimated by Totten & Irwin (1998) for these objects are respectively $-142 \pm 3$, $126 \pm 4$, $37 \pm 4$, $-44 \pm 3$, and $-113 \pm 5$ km s$^{-1}$. Heliocentric radial velocity of HE 0228-0256 is $-72$ km s$^{-1}$ (Bothun et al. 1991).

**HE 0945-0813, 1011-0942, 1127-0604, 1205-0521, 1238-0836, 1418-0306, 1428-1950, 1439-1338, 2222-2337.** The spectra of these objects show characteristics of C-R stars. The spectra of HE 1011-0942, HE 1205-0521, HE 1238-0836 match closest to the spectrum of RV Sct. The effective temperatures of the objects estimated using (J-K) calibration range from 3521 K (HE 1238-0836) to 4875 K (HE 1219-0521) as illustrated in figure 8.

The objects HE 1205-0521, HE 1238-0836 and HE 1428-1950 are also mentioned as N-type stars in the APM survey of cool carbon stars in the Galactic halo (Totten & Irwin 1998). Totten et al. (2000) have provided proper motion measurements for these objects. The distances measured by these authors assuming an average $M_R = -3.5$ for these objects are respectively 24, 16, 43, 29 and 24 kpc. Heliocentric radial velocities estimated by Totten & Irwin (1998) for these objects are respectively $-142 \pm 3$, $126 \pm 4$, $37 \pm 4$, $-44 \pm 3$, and $-113 \pm 5$ km s$^{-1}$. Heliocentric radial velocity of HE 0228-0256 is $-72$ km s$^{-1}$ (Bothun et al. 1991).
noticeable in the spectrum of HE 0945-0813. The lines due to Ba II at 6496 Å and Hα are detected in both the spectra. The molecular bands around 4733, 5165 and 5635 Å appear strongly in the spectrum of HE 0945-0813. The spectrum of HE 2222-2337 has low flux below about 4100 Å. The CH band does not appear as strong as it should be in C-R star’s spectrum. The CN band around 4215 Å is marginally detected. Other molecular bands are of similar strengths. The molecular features redward of 5635 Å are slightly weaker. We place these objects in the C-R group.

HE 0037-0654, 0954+0137, 1230-0327, 1400-1113, 1430-0919, 1447-0102, 2157-2125, 2216-0202, 2255-1724, 2305-1427, 2334-1723, 2347-0658, 2353-2314. The spectra of these objects are characterized by a weak (or absent) CN band around 4215 Å. Apart from this feature the spectra are somewhat similar to the spectrum of HD 209621.

The spectrum of HE 1230-0327 shows a strong G-band of CH and a distinct secondary P-branch head near 4342 Å. Ca I feature at 4226 Å is not detected. The CN band around 4215 Å is almost absent. While atomic lines of Ca II K, H , Hα, Na I D are distinctly seen, BaII line at 6496 Å is marginally detected. The spectra of HE 0954+0137, HE 1400-1113, HE 1430-0919, HE 2255-1724 and HE 2347-0658 look very similar to the spectrum of HE 1230-0327. In the spectra of these objects the feature due to the CN band around 4215 Å is marginally detectable. Weak molecular bands noticed in the spectrum of HD 209621 upward of 5700 Å are not observable in these spectra. Compared to HD 209621, the molecular bands around 4733, 5165, and 5635 Å are slightly weaker in the spectra of these objects. Ca II K and H are detected almost with equal strength as in HD 209621. In the spectrum of HE 1430-0919 the secondary P-branch head near 4342 Å is marginally weaker than in HD 209621. While the molecular band around 5165 Å shows a good match, the bands around 4733 and 5635 Å are marginally stronger. The spectrum in the redward of 5700 Å resembles the spectrum of HD 209621. Features due to Na I D, Hα and Ba II line at 6496 Å are detected. In the spectrum of HE 1447+0102, the CN band around 4215 Å is almost absent. Strong well defined features of Ca II K and H

![Figure 7](image.png)

Figure 7. The spectra of three dwarf carbon stars in the wavelength region 4500 - 6800 Å. Prominent features noticed in the spectra are marked on the figure.
Figure 8. A comparison of the spectra of the candidate C-N stars with the spectrum of V460 Cyg in the wavelength region 4500 - 6800 Å. The bandheads of the prominent molecular bands, Na I D and Hα, are marked on the figure.

... are seen. The C₂ molecular bands around 4733, 5165, 5635 Å are distinctly present. No other molecular bands are noticed longward of 5700 Å. The spectra of HE 2305-1427 and HE 2334-1723 show the CN band around 4215 Å with band depth almost half of that in HD 209621. All other molecular features match well with their counterparts in the spectrum of HD 209621. Weak molecular bands that are noticed in the spectrum of HD 209621 upward of 5700 Å are not noticeable in the spectra of these two objects. The features due to Na I D, Hα, and Ba II at 6496 Å could be detected. The secondary P-branch head at 4223 Å is seen as distinctly as in HD 209621.

In the spectrum of HE 2353-2314, the CH band around 4300 Å as well as the CN band around 4215 Å are marginally detected. The carbon molecular band around 5165 Å is clearly detected; the band around 5635 Å is much weaker. No other molecular bands or atomic lines are detectable. In the spectrum of HE 2255-1724, the CN band around 4215 Å is much weaker than that in HD 209621. The CH band and Ca II K and H are of similar depths. The molecular bands around 4733, 5165, 5635 Å are slightly weaker in this object. Features of Na I D, Ba II line at 6496 Å, and Hα are distinctly seen. The molecular bands longward of 5635 Å are not detectable. The spectrum acquired on Sep 11, 2008 have a better signal. In the spectrum of HE 2334-1723, the CN band around 4215 Å is much weaker than in HD 209621; all other molecular bands show a good match. The features due to Ca II K and H also show a good match. No molecular bands are detectable upward of 5700 Å. In the spectrum of HE 2347-0658 the CN band around 4215 Å is almost absent. Ca II K and H features and carbon molecular bands around 4733, 5165, 5635 Å show a good match. Molecular bands seen in HD 209621 upward of 5700 Å are not detectable in the spectrum of this object.

The spectrum of HE 1400-1113 is noisy below about 4220 Å. The CN band around 4215 Å could be marginally detected. Ca II K and H are detected as weak features. A strong CH band around 4300 Å and the secondary P-branch head near 4342 Å are distinctly seen. Other molecular features have band depths marginally weaker than their counterparts in HD 209621. Except for Na I D, Ba II at 6496 Å...
and $H_\alpha$ no other atomic lines are detected redward of 5670 Å.

The spectrum of HE 1430-0919 also shows a very weak CN band around 4215 Å. The features due to Ca II K and H are not detected. The G-band of CH around 4300 Å is however very strong in the spectrum. The spectrum of HE 2157-2125 shows the CH band around 4300 Å with almost equal strength to its counterpart in HD 209621. Features due to Ca II K and H and other molecular features are also seen with equal intensities. However, the CN band around 4215 Å is much weaker than that in HD 209621. The spectrum obtained in October, 2008 has a better signal than the spectra obtained in June and September, 2008.

The spectrum of HE 0037-0654 looks very similar to the spectrum of HD 26; however, molecular bands of C$_2$ around 4730, 5165 and 5635 Å are marginally stronger than their counterparts in HD 26. The CN band around 4215 Å is barely detected, much weaker than in HD 26. Ba II line at 6496 Å is clearly detected. Strong lines of $H_\alpha$ and Na I D are distinctly noticed. Except for the features of Ca II K and H which are much weaker, the spectrum of HE 2216-0202 is very similar to the spectrum of HD 26. The secondary P-branch head around 4342 Å is much stronger than in HD 26. The CN band around 4215 Å is not observed. The CH band at 4305 Å is not as strong as in HD 26. The molecular bands around 4733 Å and 5236 Å are of similar depths. The carbon molecular band around 5635 Å is weaker than the band around 5165 Å. No molecular bands longward of 5700 Å are detectable.

The spectrum of HE 1315-2035 is noisy blueward of 4200 Å. The G-band of CH and the carbon molecular bands near 4733, 5165 and 5635 Å are detected in the spectrum. The $H_\alpha$ feature is clearly detected. The effective temperature of this object is 4639 K as estimated from (J-K) colour calibration.

**HE 1027-2644.** The spectra of HE 1027-2644 do not show presence of any carbon molecular bands. The features due to Ca II K and H are not detected. The G-band of CH is seen as a weak feature. Features due to Ca I at 4226 Å and Na D I are seen as strong features. Ba II line at 6496 Å and $H_\alpha$ feature are detected. 2MASS JHK photometry is not available for this object.

### Table 4: Estimated effective temperatures ($T_{\text{eff}}$) from semi-empirical relations

| Star Name | $T_{\text{eff}}$(J-K) | $T_{\text{eff}}$(J-H) |
|-----------|-----------------------|-----------------------|
| HE0008-1712 | 4556.52 | 4376.94(-0.5) | 4446.43(-2.5) |
| HE0009-1824 | 5530.27 | 5377.40(-0.5) | 5443.08(-2.5) |
| HE0037-0654 | 5496.71 | 4912.74(-0.5) | 4980.33(-2.5) |
| HE0052-0543 | 3924.82 | 3831.70(-0.5) | 3896.64(-2.5) |
| HE0100-1619 | 4615.21 | 4305.94(-0.5) | 4373.23(-2.5) |
| HE0113+0110 | 4130.72 | 3973.94(-0.5) | 4039.78(-2.5) |
| HE0136-1831 | 4459.39 | 4493.10(-0.5) | 4560.81(-2.5) |
| HE0217+0056 | 2794.61 | 3053.31(-0.5) | 3110.53(-2.5) |
| HE0225-0546 | 4051.67 | 4086.82(-0.5) | 4153.25(-2.5) |
| HE0228-0256 | 3655.89 | 3916.80(-0.5) | 3982.30(-2.5) |
| HE0308-1612 | 4420.27 | 4428.17(-0.5) | 4495.77(-2.5) |
| HE0341-0314 | 4119.26 | 4336.67(-0.5) | 4404.05(-2.5) |
| HE0420-1037 | 4587.42 | 4534.65(-0.5) | 4602.42(-2.5) |
| HE0945-1434 | 4436.49 | 4738.21(-0.5) | 4806.03(-2.5) |
| HE1011-0942 | 3417.52 | 3646.15(-0.5) | 3709.67(-2.5) |
| HE1019-1136 | 2690.13 | 3140.84(-0.5) | 3199.16(-2.5) |
| HE1028-2501 | 3824.73 | 3769.05(-0.5) | 3833.54(-2.5) |
| HE1045-1434 | 4436.49 | 4738.21(-0.5) | 4806.03(-2.5) |
| HE1051-0112 | 4594.34 | 4411.69(-0.5) | 4479.26(-2.5) |
| HE1102-2142 | 4492.46 | 4383.27(-0.5) | 4450.77(-2.5) |

### 6 CONCLUDING REMARKS

An accurate assessment of the fraction of CH stars can significantly aid our understanding of formation and evolution of heavy elements at low metallicity. Another important issue is the role of low to intermediate-mass stars of the halo in the early Galactic chemical evolution. Thus large samples of faint high latitude stars such as the one reported by Christlieb et al. (2001b) that contain different types of carbon stars need to be analyzed to understand the astrophysical implications of each individual type of stellar population. Our objective in this study has been to identify the CH stars (as well as different type of stellar objects) in a selected sample of high Galactic latitude field stars. The sample is based on our on-going observational programs with HCT and VBT on cool stars. During 2007 and 2009 we have acquired low resolution spectra for a large number of stars.
| Star Name      | Teff(J-K)          | Teff(J-H)          |
|---------------|--------------------|--------------------|
| HE1110-0153   | 3969.89            | 3842.74(-0.5)      |
|               |                    | 3907.75(-2.5)      |
| HE1116-1628   | 4224.43            | 4125.85(-0.5)      |
|               |                    | 4192.46(-2.5)      |
| HE1119-1933   | 4675.25            | 4790.28(-0.5)      |
|               |                    | 4858.06(-2.5)      |
| HE1120-2122   | 4148.01            | 3961.57(-0.5)      |
|               |                    | 4027.33(-2.5)      |
| HE1123-2031   | 4365.87            | 4339.85(-0.5)      |
|               |                    | 4407.24(-2.5)      |
| HE1127-0604   | 4875.50            | 4604.60(-0.5)      |
|               |                    | 4672.42(-2.5)      |
| HE1142-2601   | 4475.87            | 4464.64(-0.5)      |
|               |                    | 4532.31(-2.5)      |
| HE1145-1319   | 4485.81            | 4514.13(-0.5)      |
|               |                    | 4581.87(-2.5)      |
| HE1146-0151   | 4515.88            | 4525.81(-0.5)      |
|               |                    | 4593.57(-2.5)      |
| HE1157-1434   | 4182.97            | 4181.08(-0.5)      |
|               |                    | 4247.93(-2.5)      |
| HE1205-0521   | 4650.36            | 4927.12(-0.5)      |
|               |                    | 4994.67(-2.5)      |
| HE1205-2539   | 4182.97            | 4046.42(-0.5)      |
|               |                    | 4112.64(-2.5)      |
| HE1228-0417   | 4795.85            | 4964.09(-0.5)      |
|               |                    | 5031.55(-2.5)      |
| HE1230-0327   | 4814.61            | 4846.74(-0.5)      |
|               |                    | 4914.44(-2.5)      |
| HE1238-0836   | 3521.23            | 3954.13(-0.5)      |
|               |                    | 4019.85(-2.5)      |
| HE1253-1859   | 4239.41            | 4105.00(-0.5)      |
|               |                    | 4171.51(-2.5)      |
| HE1315-2035   | 4639.76            | 4949.26(-0.5)      |
|               |                    | 5016.77(-2.5)      |
| HE1318-1657   | 4423.50            | 4612.48(-0.5)      |
|               |                    | 4680.31(-2.5)      |
| HE1331-2558   | 4227.41            | 4218.84(-0.5)      |
|               |                    | 4285.84(-2.5)      |
| HE1344-0411   | 3118.34            | 3414.55(-0.5)      |
|               |                    | 3475.93(-2.5)      |
| HE1358-2508   | 3623.67            | 3826.04(-0.5)      |
|               |                    | 3890.93(-2.5)      |
| HE1400-1113   | 4894.81            | 5010.94(-0.5)      |
|               |                    | 5078.27(-2.5)      |
| HE1404-0846   | 4239.40            | 4027.25(-0.5)      |
|               |                    | 4093.38(-2.5)      |
| HE1405-0346   | 4391.32            | 4484.40(-0.5)      |
|               |                    | 4552.09(-2.5)      |
| HE1410-0125   | 4378.56            | 4266.53(-0.5)      |
|               |                    | 4333.70(-2.5)      |
| HE1418-0306   | 3598.71            | 3761.98(-0.5)      |
|               |                    | 3826.41(-2.5)      |
| HE1425-2052   | 4191.80            | 4250.49(-0.5)      |
|               |                    | 4317.60(-2.5)      |
| HE1428-1950   | 4505.82            | 4573.18(-0.5)      |
|               |                    | 4640.96(-2.5)      |
| HE1429-1411   | 3057.76            | 3302.55(-0.5)      |
|               |                    | 3362.74(-2.5)      |
| HE1430-0919   | 4700.38            | 4625.80(-0.5)      |
|               |                    | 4693.64(-2.5)      |
| HE1431-0755   | 3937.98            | 3950.23(-0.5)      |
|               |                    | 4015.92(-2.5)      |
| HE1432-2138   | 5074.94            | 5075.25(-0.5)      |
|               |                    | 5142.38(-2.5)      |
| HE1439-1338   | 3658.21            | 3898.38(-0.5)      |
|               |                    | 3963.76(-2.5)      |
| HE1440-1511   | 4636.24            | 4747.85(-0.5)      |
|               |                    | 4815.66(-2.5)      |
| HE1442-0346   | 4622.20            | 4655.40(-0.5)      |
|               |                    | 4723.24(-2.5)      |
| HE1447+0102   | 5042.06            | 4893.55(-0.5)      |
|               |                    | 4961.18(-2.5)      |
| HE1525-0516   | 4546.30            | 4695.10(-0.5)      |
|               |                    | 4762.94(-2.5)      |
| HE2114-0603   | 3948.56            | 3919.97(-0.5)      |
|               |                    | 3985.40(-2.5)      |
| HE2157-2125   | 4583.97            | 5135.81(-0.5)      |
|               |                    | 5202.71(-2.5)      |
| HE2211-0605   | 4553.10            | 4621.90(-0.5)      |
|               |                    | 4689.73(-2.5)      |
The CH fraction of Carbon stars at high Galactic latitudes

Table 4: Estimated effective temperatures ($T_{eff}$) from semi-empirical relations (continued)

| Star Name | $T_{eff}$(J-K) | $T_{eff}$(J-H) |
|-----------|----------------|----------------|
| HE2213-0017 | 2701.10 | 3005.84(-0.5) |
| HE2216-0202 | 4969.45 | 5122.15(-0.5) |
| HE2222-2337 | 3911.73 | 3879.01(-0.5) |
| HE2225-1401 | 2169.18 | 2845.70(-0.5) |
| HE2226-0137 | 4369.03 | 4284.06(-0.5) |
| HE2246-1312 | 4110.70 | 4129.55(-0.5) |
| HE2255-1724 | 4075.26 | 4388.73(-0.5) |
| HE2305-1427 | 5042.06 | 4594.23(-0.5) |
| HE2334-1723 | 4729.39 | 4827.13 (-0.5) |
| HE2347-0658 | 5554.46 | 4989.70(-0.5) |
| HE2353-2314 | 3927.44 | 4014.92(-0.5) |

The numbers inside the parentheses indicate the adopted metallicities [Fe/H].

Table 5: Stars with radial velocity estimates

| Star Name | $v_t$ km s$^{-1}$ | Reference |
|-----------|--------------------|-----------|
| HE 0100–1629 | $-142.0$ | 1 |
| HE 0217+0056 | $-142.0 \pm 3$ | 2 |
| HE 0228–0256 | $-72.0$ | 1 |
| HE 1019–1136 | $-126.0 \pm 4$ | 2 |
| HE 1105–2736 | $-36.0 \pm 1.3$ | 3 |
| HE 1116–1628 | $-69.0$ | 2 |
| HE 1152–0355 | $+431.3 \pm 1.5$ | 4 |
| HE 1305+0007 | $+217.8 \pm 1.5$ | 4 |
| HE 1410–0125 | $+88.0 \pm 3$ | 5 |
| HE 1429–1411 | $-90.0 \pm 1.5$ | 6 |
| HE 1442–0658 | $-37.0 \pm 4$ | 2 |
| HE 2213–0017 | $-44.0 \pm 3$ | 2 |
| HE 2225–1401 | $-133.0 \pm 5$ | 2 |
| HD 26 | $+217.8 \pm 1.5$ | 6 |
| HD 5223 | $-244.9 \pm 1.5$ | 4 |
| HD 209621 | $-390.5 \pm 1.5$ | 6 |

References: 1: Bothun et al. (1991), 2: Totten & Irwin (1998), 3: Zwitter et al. (2008), 4: Goswami et al. (2006), 5: Frebel et al. (2006), 6: Goswami et al. (in preparation)
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