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THREE NEWLY RECOGNIZED DWARF CARBON STARS

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ABSTRACT

We confirm the identification of two faint high-latitude carbon stars with previously cataloged high proper motion objects, and report the discovery of proper motion in a third. The $R = 15.5$ star CLS 96 corresponds to LP 328-57, with $\mu = 0\farcs28$ yr^{-1}, and C*22 (Bothun et al.) is LP 765-18 = LHS 1075, with $R = 14$ and $\mu = 0\farcs62$ yr^{-1}. In addition, CLS 31, with $R = 16.5$, is found to have $\mu = 0\farcs13$ yr^{-1}. These three objects are thus inferred to be dwarf carbon stars, supplementing the one previously known case. All of these objects have *JHK* colors similar to the prototype dwarf C star, G77-61, suggesting IR colors as a useful luminosity indicator. LP 328-57 and G77-61 also share certain spectral peculiarities. Both LP 328-57 and LHS 1075 are probably at distances of ~100 pc and may have detectable parallaxes. The past assumption made by several groups (ourselves included) that faint high-latitude C stars are in the distant halo, and thus useful dynamic probes, is obviously incorrect for some yet-to-be-determined fraction of these objects.

Subject headings: stars: abundances — stars: carbon

1. INTRODUCTION

In the past few years, a small but growing number of faint ($14 < R < 17$), high-latitude stars with classical carbon star spectra have been discovered. Most have resulted from systematic searches, for example, the objective-prism survey described by Sanduleak & Pesch (1988), and we currently are completing a color-selected CCD survey for fainter objects (Green et al. 1990). One of the faintest such objects currently known, however, was discovered serendipitously (Margon et al. 1984), leading to the suspicion that there may be a significant population of faint C stars still awaiting discovery.

Although there has been little direct evidence for high luminosity of faint high-latitude C stars, it has been widely assumed that they are giants similar to the classical, bright C stars, since there are few alternative sources of the photospheric carbon other than dredge-up during post–main-sequence evolution. If this luminosity assumption is accepted, the faint high-latitude C stars are then inferred to be in the distant halo. Aside from the interesting stellar evolution questions posed by the existence of giants at Galactocentric distances of 10–100 kpc, such stars are ideal dynamical probes of the distant halo, as their sharp molecular band heads and red colors make accurate radial velocity determinations feasible with moderate-sized telescopes and CCD detectors. Because alternative halo dynamic tracers (e.g., K giants, RR Lyr stars, and globular clusters) yield poorly reconciled estimates of halo dynamical parameters, the existence of a totally independent set of distant, accurately measurable objects would be most valuable. Some initial results on halo velocity dispersions using faint C star tracers have been presented by Mould et al. (1985) and Bothun et al. (1991, hereafter B91).

To date the only known flaw in the otherwise promising technique of employing faint C stars as halo tracers has been the existence of one odd star. G77-61, a $V = 13.9$ object with a classical C spectrum, has a high proper motion (Dahn et al. 1977), and thus most certainly has luminosity at or near the main sequence. The object has subsequently been shown to be a single-lined spectroscopic binary of period 245 days and parallax $\pi_{\rm abs} = 0\farcs017 \pm 0\farcs003$ (Dearborn et al. 1986), and these authors argue that the most reasonable explanation of the prominent carbon bands in the dwarf's spectrum is photospheric deposition of mass from a now unseen companion during the companion's second ascent of the giant branch.

It has been the assumption of many workers in the field, ourselves included, that G77-61 is the result of a sufficiently rare set of circumstances that the assignment of giant luminosity to the majority of faint high-latitude C stars is still warranted. In this *Letter*, however, we describe three further dwarf carbon stars. If there are four such objects, the conclusion seems inescapable that there are more, and that faint C stars may not simply be assumed to lie in the distant halo, at least not without further evidence.

2. THE NEW CARBON DWARFS

2.1. *LP 328-57 = CLS 96*

The faint ($R = 15.5$) carbon star candidate CLS 96 was identified by Sanduleak & Pesch (1988) from objective-prism plates. For the record, we point out that the finding chart for the object published there is upside-down with respect to the orientation quoted in the caption. The curious reader may readily ascertain the probable cause of this anomaly by inverting the printed chart and noting the resulting label. The object was confirmed as a C star through slit spectra by Green & Margon (1990) and B91, the former work providing spectroscopy over a broad range, and the latter a radial velocity, +164 km s^{-1}, as well as *JHK* photometry.

The Sanduleak & Pesch (1988) paper contained a comment with a question mark appended suggesting the possible identification of CLS 96 with the previously cataloged proper-

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motion object LP 328-57 (Luyten 1974, 1979a), a star listed with $m_R = 15.4$ and coordinates about 0'.5 different from the objective-prism–selected object. At least with hindsight, the main motivation for the question mark was probably the presumption that faint C stars should not have detectable proper motions! There is also a second, slightly fainter object visible on the Palomar Sky Survey about 1' south of CLS 96, vaguely in the direction of the vector published by Luyten (1974, 1979a), so the potential for confusion of the two objects exists. The SIMBAD catalog lists the spectral type of LP 328-57 as C, simply accepting the positional association without question. Such acceptance is premature, however, at least at the time of the compilation of those data, pending verification of the objective-prism spectral type, the proper motion of the candidate, and the fact that the two stars are truly identical. The recent spectra reported by Green & Margon (1990) and B91 complete the first of these three tasks; here we report resolution of the remaining two.

We have used the digital data base assembled for the *Hubble Space Telescope* Guide Star Catalog (GSC) (Lasker et al. 1990), together with a digitization of the original Palomar Observatory Sky Survey (POSS), to provide new data on the position and proper motion of LP 328-57. On closer inspection of the images from the two epochs, not only is it evident that the high-μ object is the same as that flagged by Sanduleak & Pesch (1988), but it is also clear that the object 1' south of the candidate is a galaxy. Since the galaxy can have neither a motion nor a C spectrum, the potential for confusion of the two is removed. Through the kindness of P. Pesch, the original objective-prism plate, obtained with the CWRU Burrell Schmidt telescope at an intermediate epoch (1985.5), has been reexamined, confirming the association of the high-μ object with the star with the C spectrum.

Our astrometric data on LP 328-57 derived from Schmidt plates, using the Guide Star Selection System Astrometric Support Program (GASP), are given in Table 1. The second-epoch positions are in the frame of the *HST* GSC, a significant qualification because that system is known to differ somewhat from other astrometric frames (Russell et al. 1990). First-epoch positions are taken from POSS plates also digitized at STScI, but with preliminary plate calibrations using the SAO catalog as the reference. Internal uncertainties in the GSC (Taff et al. 1990; Russell et al. 1990) are of order 0''.5 or less; the residuals in our measurements are consistent with this value.

As a first-order correction for possible systematic differences between the solutions for the two epochs, due, e.g., to differences in reference catalogs and calibration procedures, we have also derived positions in both epochs for anonymous stars within 3' of LP 328-57. We find a well-defined, systematic offset which we have applied to our results as a correction factor. The offset for this particular field is equivalent to 0''.097 yr^{-1}. For LP 328-57 we then infer proper motion of magnitude and direction in excellent agreement with values originally quoted by Luyten (1974, 1979a), viz., μ = 0''.292 yr^{-1} at 227°, which we believe not only strengthens these original measurements but also vindicates our astrometric technique.

Given the large measured motion of LP 328-57, there can be little doubt that the object is at or near main-sequence luminosity, and is thus a dwarf carbon star. Again with hindsight, the large positive radial velocity reported for this object by B91 might have raised suspicions; it is the largest of any C star in the south Galactic pole sample.

2.2. *LHS 1075 = LP 765-18 = C*22*

JHK colors for LP 328-57 have been published by B91 and are remarkably similar to those of G77-61 (Dearborn et al. 1986), but differ from those of most other C stars. Struck by this coincidence, we have searched for proper motions in the handful of other faint C stars of similar colors.

The high-latitude, objective-prism–selected C star C*22 was first reported by B91, where *JHK* colors and a radial velocity of +56 km s^{-1} are also given. The published IR colors are similar to those of G77-61 and LP 328-57. To our knowledge, this is the only published mention of this star. However, Luyten (1979b) has previously cataloged the high-μ object LHS 1075 at virtually identical coordinates. A finding chart for this object, also known as LP 765-18 (Luyten 1979a), is given by Luyten & Albers (1979). G. MacAlpine (private communication) has kindly confirmed that this chart indicates that C*22 is indeed identical to the proper-motion object. We conclude that LHS 1075, cataloged as $R = 14$ and μ = 0''.62 yr^{-1}, is another example of a dwarf carbon star. Our updated astrometric data, again measured from the Guide Star scan

TABLE 1
ASTROMETRIC DATA FOR DWARF CARBON STARS

Property	LP 328-57	LHS 1075	CLS 31
Other names	CLS 96	LP 765-18, C*22	...
First epoch	1950.4	1953.9	1953.4
α_{2000}	$15^h52^m38^s.31$	$00^h26^m01^s.79$	$10^h54^m29^s.74$
δ_{2000}	29°28'07''.0	−19°18'41''.4	34°02'29''.4
Second epoch	1982.4	1977.8	1984.1
α_{2000}	$15^h52^m37^s.66$	$00^h26^m00^s.49$	$10^h54^m29^s.46$
δ_{2000}	29°28'02''.8	−19°18'38''.3	34°02'27''.2
μ (arcsec yr^{-1}), θ (deg)[a]	0.27, 225	0.62, 179	0.13, 202
Distance[b] (pc)	170	100	400
(U, V, W) (km s^{-1})	−140, −100, 200	−150, −240, −100	−20, −240, −60
v_{trans} (km s^{-1})	220	290	250
v_{space} (km s^{-1})	270	300	250

[a] Although the quoted (α, δ) values are the best estimates for the stellar positions at each epoch, the tabulated (μ, θ) values include corrections for external systematic errors described in the text, and thus cannot be calculated through simple subtraction of the stated positions.

[b] Distances and velocities have been estimated assuming M_K identical to G77-61 and are correspondingly uncertain.

data base as described in § 2.1, are given in Table 1, and again agree well with Luyten's original measurements.

2.3. *CLS 31*

The $R = 16.5$ C star CLS 31 was first reported by Sanduleak & Pesch (1988), with a confirming slit spectrum, IR photometry, and radial velocity of -44 km s^{-1} given by B91. Again, the IR colors are similar to those of the C dwarfs discussed above. To our knowledge this object has not been reported elsewhere or found to have a proper motion. We measured the position of CLS 31 in the Guide Star scan data base, and have derived (Table 1) a significant motion, $\mu = 0''.13$ yr^{-1}. Although this motion is small, we are confident of the accuracy of our measurement; the residuals in eight comparison stars within 4′ of the object suggest that, including corrections for external errors, this value has uncertainty of 10% or less. For all three C stars discussed in this *Letter*, this uncertainty is dominated simply by the measuring error in these stars' positions at the two epochs, which is much larger than the uncertainty in the systematic epoch offset correction. CLS 31 thus becomes the fourth known dwarf C star.

3. DISCUSSION

On an IR color-color diagram, the locus crudely defined by the three new C dwarfs discussed here, together with the previously known G77-61, is approximately $(H-K) > 0.25$, $(J-H) < 0.7$. These colors indeed fall near the mean IR color-color relation for late-type field dwarfs, which is well separated from the same relation for Galactic field giants (Aaronson & Mould 1985). Although a larger sample is needed, a reasonable inference from the current work is that for C stars a faint H-magnitude relative to J and K should serve as a warning that the usual assumption of high luminosity is dangerous.

We may crudely estimate the distance of the three newly recognized dwarfs because of their similarity in colors to G77-61, where a parallax yields $M_V = 10.1$. If the same K-band luminosity applies to these stars, we infer the distances given in Table 1. It seems clear that at least LP 328-57 and LHS 1075 should be placed on parallax programs. Using these inferred distances, our measured proper motions, and the radial velocities listed by B91, we also provide in the table preliminary space motions for all three objects. These data are consistent with all three stars being Population II objects, as is also the case for G77-61. We caution that some component of the published (single-epoch) radial velocities used for these calculations may later be recognized as due to binary orbital motion.

The similarity of the newly recognized dwarfs discussed here and G77-61 extends beyond colors. A comparison of our spectrum of LP 328-57 (Green & Margon 1990) and that of G77-61 (Dahn et al. 1977; Dearborn et al. 1986) readily shows that each exhibits an unusually strong band head of C_2 at λ6200. We believe that this resemblance may be due to strong $\Delta v = -2$ bands of $^{13}C^{12}C$, which flatten the otherwise choppy region just blueward of λ6191. Similar features have been noted in photographic spectra of ^{13}C-rich (J type) carbon stars (Gordon 1971). It is premature to speculate whether and how this relatively rare spectral feature might be linked to the peculiar luminosity or evolution of C dwarfs. It is clear, however, that if even one or two more dwarf C stars are found with this property, it will have to be viewed as fundamental to their nature. The intriguing hypothesis for G77-61 of binary evolution and hypernova processing of an extremely old (and metal-poor) dwarf (Gass, Liebert, & Wehrse 1988) argues for higher resolution spectroscopy of both LP 328-57 and LHS 1075 to determine their metallicity and ^{13}C abundances.

The detection of radial velocity variations in any or all of the three C dwarfs discussed here, when coupled with the known properties of G77-61, would suggest that binarity plays a fundamental role in the formation of dwarf C stars. Radial velocity variations in probably all giant and subgiant CH stars (McClure 1984) and as observed in G77-61 may indicate a shared heritage for these Population II C stars. Perhaps many more C giants than C dwarfs are presently known only by virtue of the much greater luminosities of the former class. Several other faint C stars make particularly promising candidates for dwarfs. For example, CLS 45 and CLS 50 (Sanduleak & Pesch 1988) have similar *JHK* colors (Mould et al. 1985) to those of the dwarfs currently known. We are now measuring proper motions over a 30 yr baseline for as many faint halo C stars as possible. Several negative results will be reported elsewhere, including CLS 23, of special interest since it is noted as a possible radial velocity variable by B91.

Since highly incomplete sky coverage has now yielded at least four dwarf C stars within a few hundred parsecs, the space density of these enigmatic objects may be significant. We might consider whether it is possible that *all* known faint, high-latitude C stars are dwarfs. This seems very unlikely, because the IR colors for many faint halo C stars are consistent with the mean color-color relation for late-type giants. Also, there are to date two known examples of dust-enshrouded, optically faint, *IRAS*–detected C stars (Cutri et al. 1989; Beichman et al. 1990) at high Galactic latitude, whose mass ejection essentially guarantees that they are asymptotic giant branch stars. We thus suspect that, as for more common spectral types, C stars of similar spectra and apparent magnitude may differ in distance by factors of 10^3, reducing their utility as dynamical tracers. Although some faint high-latitude C stars are doubtless effective probes of halo dynamics, it seems clear that considerable care will be needed in future studies to determine which ones are in fact distant objects. Infrared colors may provide one convenient luminosity discriminant.

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