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THE DISCOVERY OF TWO NEARBY CARBON DWARFS

Patrick J. Lowrance,[1] J. Davy Kirkpatrick,[1] I. Neill Reid,[2] Kelle L. Cruz,[3] and James Liebert[4]
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ABSTRACT

The comparison of optical and Two Micron All Sky Survey near-infrared photometry for large samples of cataloged proper-motion stars has given us the potential to discover previously unrecognized nearby objects of rare type. In this Letter we present the discovery of two new carbon dwarfs, LSR 2105+2514 and LP 758-43, which were drawn from proper-motion lists and which lie in a sparsely populated part of optical/near-IR color-color space. Their optical spectra, exhibiting absorptions by C_2 and/or CN, are discussed. LSR 2105+2514 is believed to lie within 200 pc and would have $M_{K_s} \geq 6.7$, making it lower in luminosity than any carbon dwarf with a measured trigonometric parallax. LP 758-43, which is not as red but still probably cooler than the best studied carbon dwarfs, is believed to lie within 360 pc. Using our optical/near-infrared selection technique on published lists of proper-motion stars, we hope in the near future to expand further the current sample of carbon dwarfs, which numbers only 31 objects at this writing.

Subject headings: stars: atmospheres — stars: carbon — techniques: photometric

1. INTRODUCTION

The distinctive optical spectra of carbon giants have led to their use as probes of the Galactic halo, especially since their bright magnitudes enable radial velocities to be obtained at very large distances (Aaronson 1983). For the first three-quarters of the last century, giants were the only luminosity class of carbon stars known. With the discovery of G77-61 (Dahn et al. 1977) at a mere 58 pc, and therefore relatively low luminosity, a category of dwarf carbon (dC) stars was finally recognized. This, however, presented a puzzle because a low-mass star is incapable of the helium fusion needed to create carbon. This puzzle was resolved by invoking the presence of an evolved, second member of the system—now an undetected white dwarf secondary. It was assumed that the second member, as it passed through its asymptotic giant branch (AGB) phase, transferred mass onto a lower mass main-sequence star, enriching it in carbon-bearing material (Dahn et al. 1977). The lower mass member was proposed to be a metal-poor subdwarf, and therefore the small amounts of oxygen it does contain in the atmosphere will be overwhelmed by the carbon. A decade after this theory was advanced, its credibility was strengthened by the discovery of radial velocity variations in G77-61 (indicating an unseen companion; Dearborn et al. 1986) and by discoveries of two other dC stars in binaries containing a visual white dwarf secondary (Heber et al. 1993; Liebert et al. 1994). A review of dC star research has been given recently by Green (2000).

The process of making a carbon dwarf may also begin to explain the existence of a rare class of carbon giants known as CH stars. CH stars are halo members with peculiar abundances, C/O > 1, and a strong overabundance of *s*-process elements thought to be produced during an AGB phase. Interestingly, they are all in known binary systems, and those with derived mass ratios are consistent with white dwarf secondaries. As such, these giant stars may represent the dC stars at a more advanced evolutionary state (McClure 1984; Wallerstein & Knapp 1998).

Our current understanding of dC stars, however, is limited by the small number of such objects now recognized. Only as more dC stars are found can we fully test the current hypotheses and understand the role of dC stars in the overall picture of stellar evolution. Fortunately, large areal photometric surveys are beginning to uncover these objects in larger numbers. Margon et al. (2002) have reported the discovery of 39 faint high-latitude carbon stars from the Sloan Digital Sky Survey (SDSS), of which 17 exhibit proper motions exceeding their 3 σ astrometric uncertainties and are assumed to be dC stars. In this Letter, we report the first two dC stars uncovered by the Two Micron All Sky Survey (2MASS).

2. THE FIRST NEW CARBON DWARF

2.1. *Discovery and Spectroscopic Confirmation*

From an analysis of multiepoch Digitized Sky Survey (DSS) images lying within 25° of the Galactic plane, Lépine, Shara, & Rich (2002, hereafter LSR02) published a list of objects having proper motions larger than 0″.5 yr^{-1} and magnitudes down to $R = 19.8$ mag. Their list, although a rediscovery of many objects tabulated in the Luyten Half-Second (LHS; Luyten 1979) catalog, also included 141 new proper-motion stars not recognized previously. Approximately 40% of those objects fall in the 2MASS Second Incremental Data Release (Cutri et al. 2000),[5] so their characteristics can be studied via diagrams employing the *B* and *R* data from the DSS as well as the JHK_s data from 2MASS. In looking at the colors of these objects, we noticed that one, LSR 2105+2514 (R.A. = $21^h05^m16^s.58$, decl. = +25°14′48″.1; J2000), has a very red $J-K_s$ color (1.28), like a late-M or early-L dwarf (Table 1), but an $R-J$ color (1.6) that is far too blue for such a dwarf. A finder chart for this object is shown in LSR02.

We observed LSR 2105+2514 spectroscopically on 2002 August 7 UT using the Double Spectrograph (Oke & Gunn 1982) on the Hale 5 m telescope at Palomar Observatory. Our instrumental setup used the D68 dichroic to split the light between the two channels at ~6800 Å. A 300 lines mm^{-1} grating

[1] Infrared Processing and Analysis Center, Mail Stop 100-22, California Institute of Technology, 770 South Wilson Avenue, Pasadena, CA 91125; lowrance@ipac.caltech.edu, davy@ipac.caltech.edu.

[2] Space Telescope Science Institute, 3700 San Martin Drive, Balitmore, MD 21218; inr@stsci.edu.

[3] Department of Physics and Astronomy, University of Pennsylvania, 209 South 33d Street, Philadelphia, PA 19104-6396; kelle@hep.upenn.edu.

[4] Department of Astronomy, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721-0065; liebert@as.arizona.edu.

[5] See http://www.ipac.caltech.edu/2mass/releases/second/doc/explsup.html.

TABLE 1
List of All Known Carbon Dwarfs

Name	R.A. (J2000)	Decl. (J2000)	J	H	K_s	$J-K_s$	Reference
LHS 1075	00 26 00.2	−19 18 52	12.54 ± 0.02	11.92 ± 0.03	11.59 ± 0.03	0.95	1
SDSS J0039373+152911	00 39 37.3	+15 29 11	…	…	…	…	2
WIE93 0041−295	00 43 34.9	−29 18 08	…	…	…	…	3
WIE93 0045−259	00 48 17.6	−25 38 38	…	…	…	…	3
SDSS J0121503+011303	01 21 50.3	+01 13 03	15.11 ± 0.05	14.25 ± 0.05	13.81 ± 0.05	1.30	2
SDSS J0125267+000449	01 25 26.7	+00 04 49	…	…	…	…	2
SDSS J0256346−084854	02 56 34.6	−08 48 54	…	…	…	…	2
G77-61 (LHS 1555)	03 32 38.0	+01 58 00	11.47 ± 0.02	10.84 ± 0.02	10.48 ± 0.02	0.99	4
SDSS J0736213+390725	07 36 21.3	+39 07 25	16.76 ± 0.14	16.09 ± 0.21	15.44 ± 0.15	1.33	2
SDSS J0822514+461232	08 22 51.4	+46 12 32	15.50 ± 0.06	14.68 ± 0.07	14.48 ± 0.09	1.02	2
SDSS J0826268+470912	08 26 26.8	+47 09 12	15.78 ± 0.07	15.19 ± 0.08	15.02 ± 0.11	0.76	2
PG 0824+289B[a]	08 27 05.1	+28 44 02	…	…	…	…	5
SDSS J0858533+012243	08 58 53.3	+01 22 43	15.82 ± 0.10	15.11 ± 0.09	14.39 ± 0.08	1.43	2
SDSS J0900114−003606	09 00 11.4	−00 36 06	…	…	…	…	2
SDSS J0948587+583020	09 48 58.7	+58 30 20	…	…	…	…	2
SDSS J1004325+004338	10 04 32.5	+00 43 38	…	…	…	…	2
CLS 29	10 40 06.4	+35 48 02	12.98 ± 0.03	12.29 ± 0.03	12.00 ± 0.02	0.98	6
CLS 31	10 54 29.6	+34 02 30	15.50 ± 0.05	15.02 ± 0.07	14.66 ± 0.08	0.84	1
KA-2	11 19 03.9	−16 44 50	13.24 ± 0.02	12.61 ± 0.03	12.48 ± 0.03	0.76	7
SDSS J1129504+003345	11 29 50.4	+00 33 45	16.47 ± 0.16	15.69 ± 0.14	15.52 ± 0.24	0.95	2
SDSS J1147317+003724	11 47 31.7	+00 37 24	…	…	…	…	2
CLS 50	12 20 00.8	+36 48 03	14.41 ± 0.03	13.93 ± 0.03	13.79 ± 0.04	0.62	8
SDSS J1353330−004039	13 53 33.0	−00 40 39	14.61 ± 0.04	13.80 ± 0.04	13.61 ± 0.05	1.00	2
SDSS J1421124−004823	14 21 12.4	−00 48 23	…	…	…	…	2
CBS 311	15 19 05.9	+50 07 03	15.56 ± 0.06	14.75 ± 0.07	14.16 ± 0.07	1.40	9
SDSS J1537322+004343	15 37 32.2	+00 43 43	15.20 ± 0.05	≥14.36	≥14.08	≥1.12	2
CLS 96 (LP 328-57)	15 52 37.5	+29 28 02	13.80 ± 0.03	13.20 ± 0.04	12.88 ± 0.03	0.92	1
WIE93 2048−348	20 52 02.6	−34 37 32	16.47 ± 0.14	15.87 ± 0.19	15.29 ± 0.16	1.18	3
LSR 2105+2514	21 05 16.6	+25 14 48	14.48 ± 0.03	13.77 ± 0.03	13.20 ± 0.04	1.28	10
LP 758-43	21 49 37.8	−11 38 28	13.00 ± 0.02	12.26 ± 0.02	11.90 ± 0.03	1.10	10
SDSS J2302550+005904	23 02 55.0	+00 59 04	15.61 ± 0.06	14.80 ± 0.06	14.60 ± 0.08	1.01	2

Note.—Photometry is from the 2MASS All-Sky Release. Those without photometry were too faint for 2MASS. The carbon dwarfs with determined parallaxes (Harris et al. 1998) are G77-61 ($\pi_{\rm trig}$ = 16.9 ± 2.2 mas; M_{K_s} = 6.62), LHS 1075 ($\pi_{\rm trig}$ = 7.96 ± 0.84 mas; M_{K_s} = 6.09), and CLS 96 ($\pi_{\rm trig}$ = 4.54 ± 0.66 mas; M_{K_s} = 6.17). Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

Discovery References.—(1) Green & Margon 1994; (2) Margon et al. 2002; (3) Warren et al. 1993; (4) Dahn et al. 1977; (5) Heber et al. 1993; (6) Totten, Irwin, & Whitelock 2000; (7) Ratnatunga 1983; (8) Green et al. 1992; (9) Liebert et al. 1994; (10) this Letter.

[a] Photometry does not split into two sources in the 2MASS All-Sky Release. The combined photometry is J = 12.42 ± 0.03, H = 11.80 ± 0.04, and K_s = 11.65 ± 0.03.

was used in the blue arm, and a 316 lines mm^{-1} grating in the red arm, with grating tilts that provided a few hundred angstroms of duplicate coverage between the two arms. This provided continuous wavelength coverage from 3800 to 9100 Å. Use of a 2".0 slit resulted in a resolution of 8 Å. Observations were reduced using standard techniques following Kirkpatrick, Henry, & McCarthy (1991) and flux-calibrated using the standard star Feige 110 (Hamuy et al. 1994).

The resulting spectrum is shown in Figure 1. The strong bands of C_2 at 4382, 4737, 5165, 5636, and 6191 Å are easily recognizable, indicating that this is a carbon star. The high proper motion measured by LSR02 of 0".563 yr^{-1} along with its magnitudes of B = 18.7 ± 0.5 and R = 16.1 ± 0.5 indicate that LSR 2105+2514 is a dwarf star and not a background giant.

2.2. *Known Carbon Dwarfs and a Comparison with LSR 2105+2514*

In a given volume of space, carbon dwarfs are believed to greatly outnumber carbon giants and as such should be the dominant type of carbon star in the Galaxy (Green 2000). Nonetheless, few dC stars are cataloged. Before the 17 dC stars recently announced by Margon et al. (2002), previous discoveries only dribbled in since the 1970s. Table 1 gives a list of all dC stars known as of this writing.

Only three of the carbon dwarfs in Table 1 have known distances, and the faint magnitudes and presumably larger distances of many of the others may preclude a robust trigonometric parallax determination. LSR 2105+2514 is bright enough that it has already been added to the USNO parallax program. Even without a $\pi_{\rm trig}$, however, we can place a crude upper limit to its distance based on its measured proper motion of 0".563 yr^{-1} and θ = 150°.2 (LSR02). Assuming that LSR 2105+2514 is gravitationally bound in the Galaxy, it cannot exceed an escape velocity of ~500 km s^{-1} (Carney, Latham, & Laird 1988). We then calculate expected (U,V,W)-motions, stepping out in distance assuming $V_{\rm rad}$ = 0. We have transformed those velocities to galactic motions using a solar motion of (9, 11, 6) and assuming a rotational velocity of 220 km s^{-1} for the local standard of rest. LSR 2105+2514 has a total velocity exceeding 500 km s^{-1} if the distance exceeds 200 pc. That suggests that LSR 2105+2514 has $M_{K_s} \geq 6.7$ mag. This would indicate a lower luminosity carbon dwarf than any of the ones with a measured $\pi_{\rm trig}$ (see Table 1). This suggestion is seemingly supported by its red $J-K_s$ color of 1.28, which indicates that it is also one of the coolest carbon dwarfs.

3. FINDING OTHER CARBON DWARFS

Currently, the only way to distinguish between a carbon dwarf and a carbon giant is through its luminosity, and hence one needs a measure of the parallax or an indirect distance indicator such as proper motion. To date, discriminators based

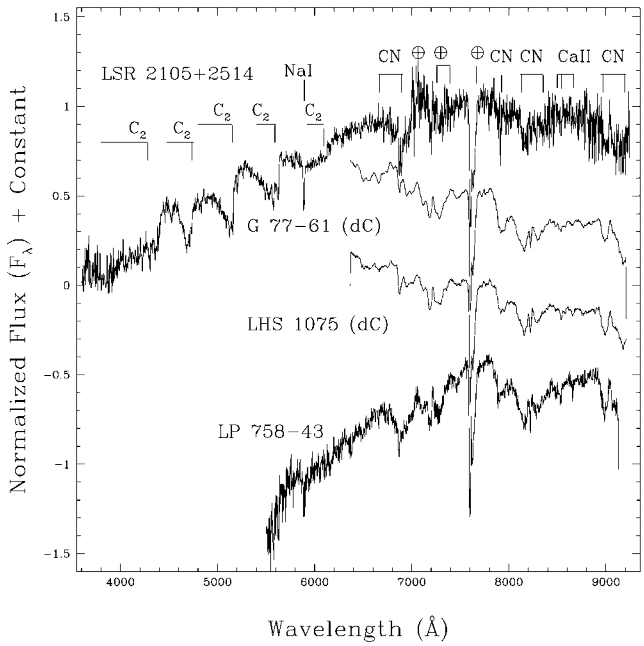

FIG. 1.—Optical spectra of LSR 2105+2514 (*top*) and LP 758-43 (*bottom*) compared with known carbon dwarfs G77-61 and LHS 1075 from Kirkpatrick (1992). The Swan bands of C_2 at 4382, 4737, 5165, and 5636 Å are labeled as well as the sharp band head of C_2 at 6191 Å not often seen in carbon giants. The Na I "D" doublet, Ca II triplet, and the CN bands are also labeled. In the LSR 2105+2514 spectrum, there was a small calibration problem in the blueward side of the red channel (~6800–7200 Å) that caused the flux in that region to be incorrectly elevated. This small portion is suspect, but the remainder of the spectrum should not be affected. The spectra are all normalized at 7500 Å, and offsets of −0.5, −1.0, and −1.5 have been applied to the normalized flux levels of G77-61, LHS 1075, and LP 758-43, respectively, to separate them from each other in the figure.

on spectroscopy or photometry have been proposed, but none have met with 100% success.

To define a list of carbon dwarf candidates, we have chosen the list of 36,085 New Luyten Two-Tenths (NLTT) catalog objects (Luyten 1980) that Salim & Gould (2003) have cross-referenced against the 2MASS Second Incremental Data Release. Using the listed USNO-A *R* magnitudes, if we plot known carbon dwarfs on an $R-J$ versus $J-K_s$ diagram along with objects from the NLTT catalog, we find that carbon dwarfs generally have much redder $J-K_s$ colors than the cloud of main-sequence stars at similar $R-J$ colors (Fig. 2). Examining the infrared spectra of carbon dwarfs in Joyce (1998), we find shallow CN bands at *R* and *K* along with the *K*-band CO absorptions that are normally in low-mass stars, but a defining characteristic of these carbon dwarfs is their large CN absorption bands at *J*. This results in bluer $R-J$ and redder $J-K_s$ colors than main-sequence objects of similar temperature have. Exploring objects from the NLTT catalog in this part of color space should increase the sample size of known carbon dwarfs.

Objects with infrared colors are often placed on $(J-H)$/$(H-K_s)$ to decipher between the giant and dwarf populations. Unfortunately, as Margon et al. (2002) comment and Figure 3 demonstrates, some of the carbon dwarfs have $J-H$ colors like giants have, and therefore they cannot be distinguished using this diagram alone. Likewise, there are a few unusual giants that fall in the lower half of the diagram along with the bulk of the dwarfs. It is therefore important to search for *spectroscopic* indicators that might help us to understand if these differences are due to temperature or abundance effects and to possibly differentiate carbon dwarfs from carbon giants.

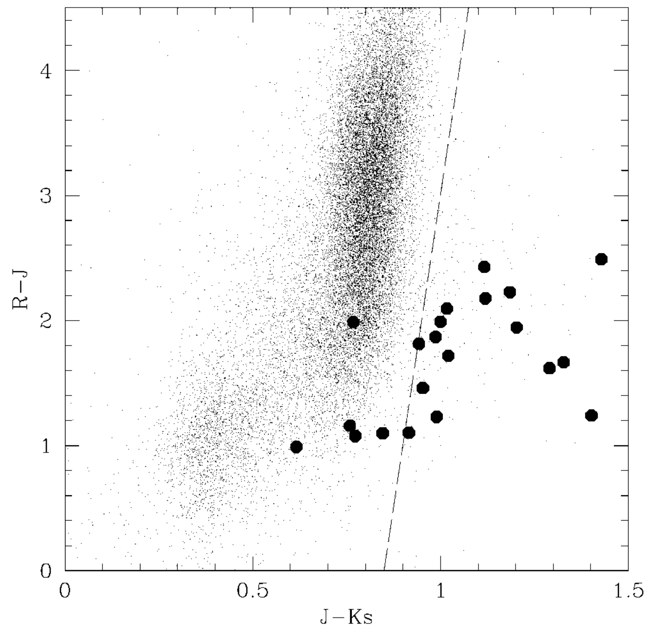

FIG. 2.—$R-J$ vs. $J-K_s$ for stars from Salim & Gould (2003) with the known carbon dwarfs (*filled circles*). The dashed line represents a boundary of $(J-K_s) = 20(R-J) - 17$, used to define a cutoff for the observational selection of possible carbon dwarfs.

4. A SECOND NEW CARBON DWARF

Using the $R-J$ versus $J-K_s$ selection criteria outlined above and in the caption to Figure 2, we have identified and observed several NLTT carbon dwarf candidates. LP 758-43, with

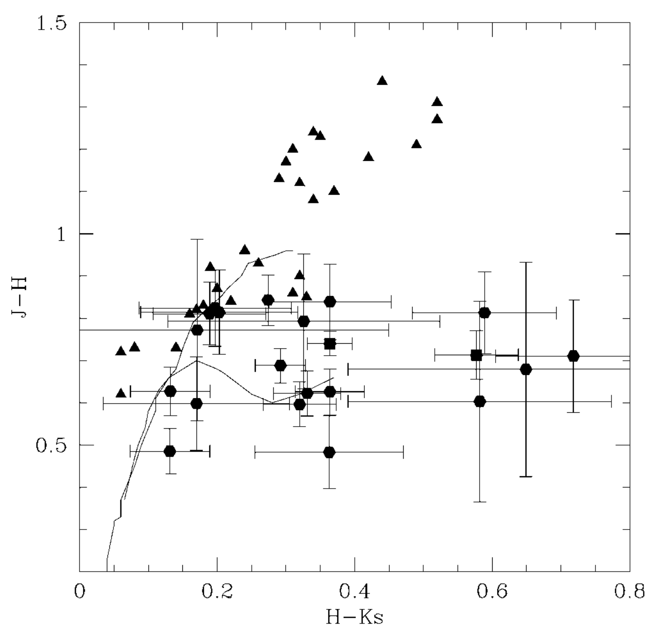

FIG. 3.—$J-H$ vs. $H-K_s$ for the two discoveries in this Letter (*filled squares*) and all 2MASS photometered carbon dwarfs (*filled hexagons*; the two with error bars greater than 0.2 have been omitted here) listed in Table 1 compared with carbon giants (*filled triangles*). Overplotted are the Bessell & Brett (1988) tracks for giants (*top*) and dwarfs (*bottom*). Note that some of the carbon dwarfs fall within the giant branch of these Bessell-Brett tracks, leading to confusion for objects with small or no proper motion.

$R-J = 2.0$ and $J-K_s = 1.10$, was observed on 2002 September 26 UT with the Multi-Aperture Red Spectrograph on the KPNO Mayall 4 m telescope. We used the VB8050-450 grating and a 2″.0 wide long slit, covering the wavelength range 5600–10000 Å at a resolution of ∼9 Å. The data were reduced and wavelength-calibrated using standard techniques in IRAF and flux-calibrated through observations of the spectrophotometric standard star Feige 110. The spectrum of LP 758-43 is plotted in Figure 1 and compared with other known carbon dwarfs. The CN bands appear very similar in depth to the previously known carbon dwarfs. A finding chart for LP 758-43 is presented in Figure 4. Other candidates that turned out to be close doubles, mismatches with reddened stars, a white dwarf/red dwarf binary, and M dwarfs will be summarized in the complete survey (P. J. Lowrance et al. 2003, in preparation).

With $K_s = 11.90$, LP 758-43 is one of the brighter examples of a dC star (see Table 1), enabling future trigonometric parallax measurements. Without a π_{trig}, we can attempt to place a crude upper limit to the distance applying the arguments used for LSR 2105+2514. For its measured proper motion of 0″.255 yr^{-1} and $\theta = 90.4$ not to exceed the escape velocity of ∼500 km s^{-1}, its distance would be no greater than ∼360 pc with $M_{K_s} > 4.1$ mag. The $J-K_s$ color of LP 758-43 ($J-K_s = 1.1$) is redder than the average $J-K_s$ color ($J-K_s = 0.95$) of the three carbon dwarfs with known distances. Those three have an average $M_{K_s} = 6.5$ mag, so if we assume LP 758-43 has a similar or fainter absolute magnitude at K_s, it is more likely located at less than 120 pc.

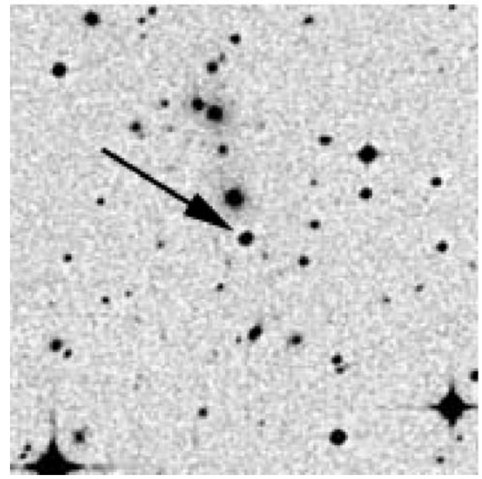

FIG. 4.—Finder chart for LP 758-43. The 5′ × 5′ *R*-band image is from the SDSS (epoch 1988 October 9), where an arrow distinguishes the carbon dwarf.

5. CONCLUSIONS

We present the optical spectra of two newly discovered carbon dwarfs, LSR 2105+2514 and LP 758-43, with proper motions of 0″.563 yr^{-1} and 0″.255 yr^{-1}, respectively. Both objects were selected based on their unusual optical-to-infrared colors and lie in a locus on the optical/near-infrared color-color diagram populated by other known carbon dwarfs. Looking through proper-motion catalogs—in which it is assured that faint objects are nearby dwarfs and not background giants—for objects of similar color will allow us to produce lists of carbon dwarf candidates for spectroscopic follow-up. Finding more carbon dwarfs, of which only 31 are currently known, can help us understand the role of dC stars in stellar evolution. Finally, broadening the sample will allow a search for spectroscopic discriminants that could help distinguish between carbon dwarfs and carbon giants.

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