SPECTRAL CLASSIFICATIONS FOR NEW OR PREVIOUSLY UNCLASSIFIED CARBON STARS

C. B. STEPHENSON
Warner and Swasey Observatory, Case Institute of Technology
Received March 19, 1965

ABSTRACT

New spectral classifications are presented for 112 stars whose objective prism spectra show absorption features due to C_2 or to very strong red CN; 102 of these are newly identified red carbon stars. Division into spectral types R and N has been possible in many cases A previously recognized variation in the relative numbers of N- and R-type stars with galactic longitude is reinforced. Five additional stars are suggested to belong to the group whose members, like GP Ori and R CMi, combine carbon and S-type spectral features; identification charts are furnished for the non-BD stars among the suggested new members of this group.

I. INTRODUCTION

The objective prism plates of Regions IV and VI of the *Luminous Stars in the Northern Milky Way* (hereinafter cited as "*LS*") catalogues (Nassau and Stephenson 1963; Nassau, Stephenson, and MacConnell 1965) have furnished identifications of considerable numbers of previously unknown carbon stars as well as additional spectral data for some known carbon stars. These surveys included plates of the blue spectral region (3300–4900 Å on Kodak IIa-O emulsion, dispersion 580 Å mm^{-1} at $H\gamma$) and of the red region (5800–6800 Å on 103a-F, mean dispersion $\sim$1000 Å mm^{-1}). Many carbon stars as faint as $m_{pg} = 13$ could be segregated into the R and N spectral classes with the aid of the blue-region plates, while the red plates permitted identification of objects having very strong cyanogen bands—such objects in practice almost always being classical carbon stars—to visual magnitude 14.

The most general carbon-star survey in recent years was one of the entire northern Milky Way conducted at the Warner and Swasey Observatory, using unsensitized infrared plates and short exposures (Nassau and Blanco 1954, 1957*a;* Blanco 1958). The limiting infrared magnitude for carbon stars on the *LS* red plates is comparable to or exceeds that ($m_i \sim 10$) of the earlier infrared survey in the case of all but the reddest stars, and even the blue plates serve to identify some types of carbon stars either not classifiable upon or not reached by the plates of the infrared survey. The survey now being reported covers only about 70° of galactic longitude, but its latitude limits exceed those of the infrared survey in most longitudes.

The results of the writer's examination of the carbon star spectra on the *LS IV* and *VI* plates are presented below.

II. NEW CARBON STARS

Table 1 lists carbon stars not previously designated as such. The magnitudes given in this and the following tables are photographic unless accompanied by the symbol "v," in which case they are visual. The former have a probable error of about $\frac{1}{3}$ mag., while that of the visual magnitudes is upward of 1 mag. The magnitudes are based upon eye estimates of spectral image densities.

The stars classified as carbon on the basis of the blue spectral region all show the Swan band of C_2 with band head at 4737 Å. Those designated carbon only on the basis of the red plates show strong cyanogen bands or, when the bands themselves are not individually discernible, have the characteristic form of the apparent continuum that is produced by strong CN absorption in the red (cf. Nassau and Stephenson 1960). The stars classed

TABLE 1

NEW CARBON STARS

BD	α(1900)	δ(1900)	l^{II}	b^{II}	Mag	Spec	Remarks
	$5^h25^m58^s.8$	+15°21′04″	189°.8	− 9°.9	13 6	N	
	5 26 45 3	+15 40 24	189 7	− 9 5	14 0	N	
	5 37 55 4	+10 01 38	196 0	−10 2	13 1	N	
	5 40 00 3	+12 13 48	194 3	− 8 6	14 0	N	QS Ori*
	5 42 00 6	+ 5 05 08	200 9	−11 8	11 0:	R:	
	5 58 18 1	+12 57 45	196 0	− 4 4	13 3	N	
	6 01 24 4	− 8 29 50	215 5	−13 9	12 5	N	
	6 01 49 5	+ 0 29 23	207 4	− 9 7	11 5 v		
−4°1365	6 02 10 9	− 4 34 59	212 0	−12 0	10 6		λ 4737 barely visible
+9°1097	6 02 15 7	+ 9 14 57	199 7	− 5 4	10 5:		May not be true carbon†
	6 05 28 8	+ 8 10 10	201 0	− 5 2	12 5 v		Very red
	6 10 42 5	− 1 44 59	210 4	− 8 8	12 5 v		
	6 13 45 2	+ 9 13 42	201 1	− 2 9	14 0:	N:	
	6 14 25 0	+ 1 32 12	208 0	− 6 4	13 5	R:	
−0°1257 sp	6 14 25 5	− 0 43 11	210 0	− 7 4	12 5 v		
	6 14 30 5	+ 5 22 02	204 6	− 4 6	10 0:	N:	
	6 15 33 0	+11 36 50	199 2	− 1 4	12 5 v		
	6 17 13 9	− 5 57 38	215 0	− 9 2	11 5 v		
	6 17 37 8	+12 12 13	199 0	+ 0 2	12 5 v		Red
	6 24 03 6	+ 7 13 33	204 0	− 1 6	13 5:	N:	
	6 29 37 3	+ 4 55 15	206 7	− 1 4	14 0 v		
	6 30 39 2	+ 6 09 47	205 8	− 0 6	12 6:v		Very red
	6 31 44 4	+ 1 17 37	210 2	− 2 7	14 0 v		
	6 33 33 8	− 0 44 22	212 2	− 3 2	13 5 v		
	6 35 18 5	+12 40 20	200 5	+ 3 4	11 9 v		
	6 37 08 0	+ 6 17 45	206 4	+ 0 8	13 5 v		
	6 38 36 8	− 2 15 48	214 2	− 2 8	13 2 v		
	6 39 06 4	+ 2 01 02	210 4	− 0 7	13 2 v		
	6 45 21 3	− 2 47 00	215 4	− 1 6	13 1 v		
	6 47 55	+ 4 24:	209 3	+ 2 4	12 9		λ 4737 is weak
	6 49 21 0	+10 58 09	203 6	+ 5 7	12 3 v		Fairly strong D-line
	6 50 37 7	− 2 12 40	215 5	− 0 1	13 2 v		
	7 04 31 1	+ 2 02 42	213 3	+ 4 9	12 5 v		Fairly strong D-line
	7 07 05 1	+ 2 03 47	213 6	+ 5 5	12 5 v		
	7 12 23 6	− 0 27 41	216 5	+ 5 5	11 5 v		
	7 14 01 5	− 1 37 08	217 7	+ 5 3	13 1	N	
	7 19 27 9	− 0 44 59	217 6	+ 6 9	10 3 v		
	7 19 41 8	− 4 26 11	220 9	+ 5 2	13 5 v		
	7 21 15 3	− 4 59 25	221 5	+ 5 3	13 1		
	7 21 05 9	− 3 50 13	220 5	+ 5 8	10 3 v		Strong D-line
	7 21 33 9	+ 2 37 51	214 8	+ 9 0	12 3 v		
−2°2120	7 22 33 6	− 2 56 34	219 9	+ 6 6	12 4	N:	
	7 25 53 2	+ 4 24 14	213 7	+10 8	11 6	N	Sanford bands
	7 26 28 6	− 2 45 08	220 2	+ 7 5	13 7	N	
	7 27 27 4	− 4 09 04	221 5	+ 7 1	12 7 v		
	7 34 24 1	− 1 55 21	220 4	+ 9 7	12 7	N:	
	7 41 36 5	− 8 04 41	226 7	+ 8 2	12 9		
	7 46 11 5	− 2 21 59	222 2	+12 0	12 7 v		
	7 50 43 1	− 2 56 05	223 3	+12 7	12 7	N	
	7 55 15 2	− 4 30 15	225 3	+13 0	11 0	R0	
	16 13 03 7	− 7 57 03	5 3	+28 7	13 4 v		Red
	16 13 58 9	− 3 19 56	9 8	+31 3	12 3	R0	
−4°4135	16 31 48 7	− 4 13 27	11 9	+27 1	12 0	R0	
	16 54 30 1	− 2 38 37	16 7	+23 1	13 3	R:	
	17 11 52 0	+11 59 06	33 2	+26 4	12 9	R	

* Very strong D-line

† Objective prism blue-region spectrum resembles HD 113801 (Cl_1), called intermediate between R and K in HD 130 Å mm^{-1} spectrogram does not confirm C_2 λ 4737 and suggests the object is merely an extremely strong cyanogen star.

TABLE 1—*Continued*

BD	α(1900)	δ(1900)	l^{II}	b^{II}	Mag	Spec	Remarks
	$17^h13^m24^s8$	−11°04′38″	11°8	+14°7	14 2 v		
	17 19 28 9	+ 5 16 51	27 5	+21 7	13 0 v		
	17 23 13 6	+ 7 41 55	30 3	+22 0	12 4		λ 4737 weak; strong infrared CN
+2°3336	17 26 20 5	+ 2 03 04	25 3	+18 7	11 1		
	17 34 30 0	− 4 17 44	20 6	+13 8	13 5 v		
	17 36 56 0	+ 1 39 14	26 3	+16 2	12 3 v		
	18 02 02 3	−11 13 29	17 9	+ 4 4	13 2 v		
	18 16 10 0	+ 5 20 09	34 3	+ 9 2	11 9 v		
	18 21 27 3	−11 50 29	19 7	0 0	13 1	R:	
	18 21 52 1	− 1 09 46	29 2	+ 4 9	13 2 v		
	18 24 56 0	− 9 52 04	21 8	+ 0 2	13 2 v		
	18 32 22 9	−10 59 14	21 7	− 2 0	13 5 v		
	18 34 16 6	−14 15 59	19 0	− 3 9	12 4	R	
	18 35 09 2	−10 06 44	22 8	− 2 2	13 2	N:	
	18 35 17 3	− 5 00 19	27 3	+ 0 2	13 7 v		
	18 42 16 0	− 4 43 07	28 4	− 1 2	13 0 v		
	18 46 54 0	−13 54 33	20 7	− 6 5	12 8	R	
	18 51 15 2	− 3 18 42	30 7	− 2 6	13 5 v		
	18 55 18 2	− 5 27 28	29 2	− 4 5	13 0 v		
	19 01 09 7	− 5 27 58	29 9	− 5 8	10 7 v		
	19 01 21 5	+ 5 31 13	39 7	− 0 7	13 1 v		
	19 02 00 9	− 2 57 57	32 2	− 4 8	12 8	N	Red
	19 11 20 6	+ 6 44 10	41 9	− 2 3	13 4 v		
	19 13 11 1	+ 8 42 21	43 9	− 1 8	11 8 v		
	19 13 24 2	+ 1 46 25	37 8	− 5 1	11 8 v		
	19 16 27 6	+ 7 27 57	43 2	− 3 1	12 2 v		
	19 16 44 2	− 7 01 40	30 3	− 9 9	12 5 v		
	19 18 14 6	+ 2 36 55	39 1	− 5 8	12 8 v		
	19 20 55 0	+ 4 14 10	40 8	− 5 6	13 4	R8	
	19 21 21 7	− 1 14 48	36 0	− 8 3	13 1	R	
	19 27 13 4	− 0 24 15	37 5	− 9 2	12 7	R:	ES Aql
	19 27 24 3	+ 0 49 13	38 6	− 8 6	12 5	R0	Weak G band
	19 29 31 9	− 2 24 37	35 9	−10 6	12 9	R	
	19 30 17 8	− 6 09 44	32 6	−12 5	12 7	R	
	19 30 48 2	−11 03 31	28 2	−14 8	12 9 v		
	19 34 04 3	+ 7 44 02	45 5	− 6 8	12 5 v		
	19 40 44 7	+ 4 29 07	43 4	− 9 8	12 4	R	
	19 44 39 4	+ 3 31 28	43 1	−11 1	12 5	N:	Red
−7°5141	19 55 42 3	− 7 38 19	34 2	−18 8	12 1		
	20 04 20 1	− 5 45 40	37 0	−19 9	13 4	N:	
	20 13 47 6	−12 42 42	31 4	−25 0	13 8	R::	
	20 14 44 7	+ 4 45 14	48 0	−17 0	13 1	R	
	20 25 33 1	+ 3 06 13	48 0	−20 2	12 7	R:	
	20 33 41 1	+ 4 03 19	50 0	−21 4	12 4	R1	
	20 48 27 4	+ 1 14 19	49 5	−26 0	13 2	R	
	20 49 48 8	+ 7 42 44	55 7	−22 8	11 4	R	
+10°4455	20 59 12 3	+10 13 54	59 4	−23 2	11 7	R	

as carbon stars on the basis of the red plates are identifiable in Table 1 by the fact that visual magnitudes are given for them.

No attempt at subclassification was made on the basis of the red spectral region. Experience with the brighter stars suggests that it is about four times as probable that an N-type star of a given red magnitude will be recognized as a carbon star on the red plates as that an R-type star of the same red magnitude will be so identified. In a few cases we have recorded the presence of a strong sodium D-line, which should indicate that the spectral type is very late in the classification system of Keenan and Morgan (1941). It is unfortunate that nearly all of the red plates of *LS IV* (right ascensions 16^h–20^h in Table 1) were taken through a filter that did not pass the spectral region of the D-lines. Stars appearing exceptionally red in the red region are indicated in Table 1 by the remark "red."

TABLE 2

STARS THAT MAY COMBINE S AND CARBON CHARACTERISTICS

Star	α(1900)	δ(1900)	Mag	Remarks
	$5^h56^m25^s.2$	$+6°38'03''$	13 5	Similar to BD $-8°1900$ Spectrum may be variable. Blue continuum like many S stars, with suggestion of weak, narrow λ 4737 on one plate. Strong D-line, with suspicion of λ 6474 ZrO
Case 598	6 26 02 1	-5 26 37	11 7 v	Red region similar to R CMi. Called a carbon star by Nassau and Blanco (1957*a*) on basis of infrared cyanogen Blue region shows no trace of λ 4737 C_2
V 372 Mon	6 36 29 3	-4 30 22	$\sim$12 5	ZrO λ 6474 weak but definite. Strong D-line. Classified S by Nassau and Blanco (1957*b*) on the basis of infrared LaO. They noted that the star showed evidence of cyanogen bands in the infrared CN is probably also weakly present in the red region, particularly the (4, 0) red-system group near λ 6200
$-8°1900$	7 20 13 9	-8 05 24	11 8	Similar to $5^h56^m25^s.2$ in blue and red, but shows definite λ 6474 ZrO. Reported as type N by Mayall (1951)
Case 621	18 54 58 5	-1 43 14	13 0:	Perhaps similar to R CMi. Called carbon in Case infrared survey, but λ 4737 not visible. Hβ was in emission on June 13 and July 7, 1959; magnitude is variable

Most of the spectra observed in the blue region have been subdivided into types R and N. Further subdivision was attempted in only a few cases of obviously very early or very advanced R-type stars. Several of the blue-green bands discussed by Sanford (1926), Shane (1928), and others, of unidentified origin until Kleman (1956) proposed that they are due to SiC_2, are observable on our blue-region plates; in objects like RY Draconis and V Aquilae the bands are outstanding. In the remarks to our tables these bands have been referred to as "Sanford bands."

III. STARS COMBINING CARBON AND S-TYPE CHARACTERISTICS

It is of considerable interest that our data suggest several candidates for addition to the small and highly interesting group of stars whose spectra resemble that of GP Orionis or R Canis Minoris (cf. Bidelman 1950, 1954; Keenan 1954). Table 2 lists these stars ("Case" numbers referring to infrared survey lists in the references mentioned in the Introduction), and Figure 1 gives identification charts for the non-BD stars. The star

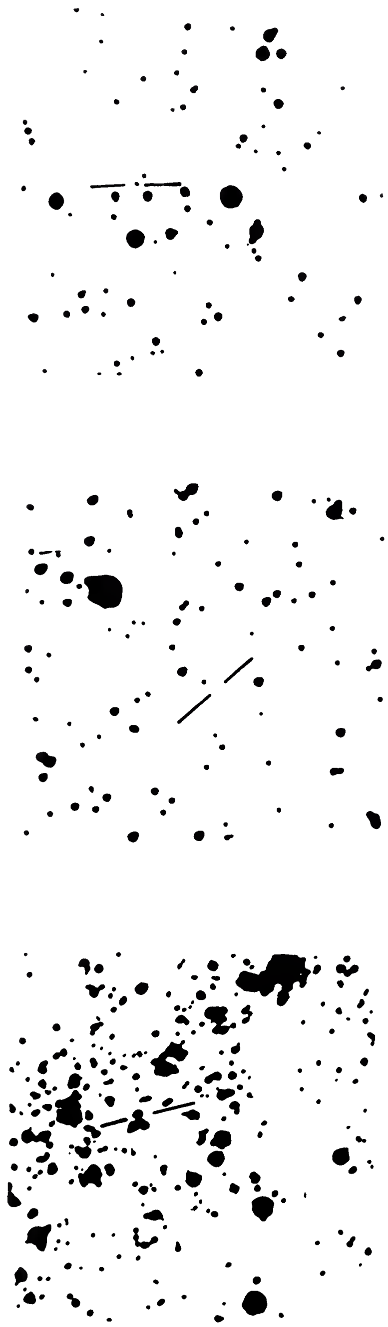

FIG. 1.—Identification charts for the non-BD stars of Table 2, reproduced from the *Lick Sky Atlas*. North is at the top and east to the left; the fields are ~30′ × 30′. *Top*: $5^{h}56^{m}25^{s}.2$. The brightest image in the field is BD + 6°1087. *Center:* Case carbon star No 598. The brightest star is BD − 5°1666. *Bottom:* Case carbon star No. 621. The brightest star, near the northern edge of the field in the northwestern quadrant, is BD − 1°3613.

V 372 Mon was previously suspected to be such a star by dint of the presence of LaO and probable CN in the infrared (Nassau and Blanco 1957*b*), but our data strengthen its candidacy.

IV. ADDITIONAL DATA FOR KNOWN CARBON STARS

Table 3 presents miscellaneous information for known carbon stars. "Dearborn" numbers refer to the catalogue of Lee, Baldwin, Hamlin, and Kinnaird (1940).

V. GALACTIC DISTRIBUTION

The difference in the relative numbers of N- and R-type stars between *LS IV* (Scutum-Aquila) and *LS VI* (Orion-Monoceros) is remarkable. That type N stars far outnumber those of type R in the Monoceros region has long been known (cf. Lee, Gore, and Bartlett 1947), although the difference noted by the Dearborn observers would have been still more striking had six stars in the Monoceros area classified R by them been called N as they were by the writer (five of these have been classified as type N by Sanford; the sixth occurs in Table 3). Another concentration of N-type stars exists in Cygnus. Such variations with longitude together with the greater galactic concentration of the N stars have led to the suggestion that the stars of type N are affiliated with the galactic spiral structure (cf. Blanco 1965). Even if the N stars are not spiral-arm tracers, the variation in N:R ratio with galactic longitude and latitude clearly indicates the existence of a meaningful evolutionary difference between these two spectral groups, as was long ago suggested by radial velocity studies (Sanford 1944) and confirmed by quite recent velocity analyses (Dahn 1964).

TABLE 3

NEW OBSERVATIONS OF PREVIOUSLY KNOWN CARBON STARS

Star	α(1900)	δ(1900)	Mag	Remarks
Case 406 .	$6^h48^m08^s.6$	$+7°17'57''$	12 7	N
Dearborn 76. .	6 55 09 7	+ 5 20 10	12 6	N; called R in Dearborn catalogue
KL Mon = Case 736	6 58 18 5	+ 9 03 13	13 1	N
Dearborn 82 = +5°1606	7 10 20 0	+ 5 14 08	12 6	Strong Sanford bands, like V Aql
Case 23 = +10°3764	18 57 30 9	+10 05 52	12 3	N; so classified previously, but more uncertainly, from infrared
Dearborn 135	19 35 24 9	+ 8 48 08	12 3	Dearborn declination is 9′ in error; Sanford (1944) was therefore not aware that he had observed a Dearborn star

It is noteworthy that the present survey suggests that the large value of the N:R population ratio within a given limiting magnitude in Orion-Monoceros persists to considerably fainter magnitudes than those formerly observed. Including uncertain classifications, in this paper twenty-five carbon stars within 11° of the galactic equator have been assigned new classifications of R or N; the interesting fact is that among these new classifications the ratio of numbers of N stars to those of type R is 13:1 in *LS VI*, while in *LS IV* it is 2:9. In both regions the new stars have quite comparable distributions in apparent magnitude. The corresponding ratios for all carbon stars having classifications of N or R in these two low-latitude regions is now about twelve for *LS VI* (40 stars) and is near unity for *LS IV* (25 stars).

Since the R-N classifications depend upon the information contained within a common spectral interval of only about 300 Å, it is extremely improbable that this variation with longitude can be explained through any effects of variation in the wavelength dependence of interstellar absorption. The absolute magnitudes of the carbon stars are poorly known, but the photographic absolute magnitudes of the two groups are probably quite similar (cf. Blanco 1965) so that variations in the total interstellar absorption are also unlikely to be a fundamental factor. As to possible correlation of our longitude effects with spiral-like galactic structure, we may note that in the *LS VI* region the only noteworthy feature of optical or semi-optical spiral-like structure in the more commonly cited diagrams (Morgan, Code, and Whitford 1955; Bok 1959) is Bok's "Orion spur," which extends to greater distances from the Sun than those probably reached in our blue survey. That the Monoceros concentration of N stars may be closely related to any details of spiral-like galactic structure is, apart from any other objections, made doubtful by the considerable extension of the concentration in latitude. Even if the photographic absolute magnitudes of the carbon stars are as faint as $+2.5$ (cf. Blanco 1965) the fainter and higher-latitude N stars in *LS VI* are upward of 150 pcs from the galactic plane.

The variation with galactic longitude in the relative numbers of N- and R-type stars, which are essentially stars of two slightly different temperature groups (Keenan and Morgan 1941), at distances from the Sun mainly less than 1 kpc is an observational fact. Its explanation should prove to be of considerable interest.

The equatorial coordinates of the stars tabulated in this paper have been obtained through the labors of individuals, mostly Case Institute students, too numerous to acknowledge, and through the availability of Case Institute's Andrew R. Jennings Computing Center, which has the support of National Science Foundation grant GP642. The long support of the Office of Naval Research for the objective-prism surveys of which this investigation has been a result is gratefully acknowledged.

REFERENCES

Bidelman, W. P. 1950, *Ap J.*, **112**, 219.
———. 1954, *Inst d'ap. Liège Mém. 8°*, No 357.
Blanco, V. M. 1958, *Ap. J.*, **127**, 191
———. 1965, *Stars and Stellar Systems*, ed A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), Vol **5**, xii.
Bok, B J. 1959, *Observatory*, **79**, 58.
Dahn, C. C. 1964, *Pub. A.S.P.*, **76**, 403
Keenan, P. C. 1954, *Ap. J.*, **120**, 484.
Keenan, P. C , and Morgan, W. W. 1941, *Ap. J.*, **94**, 501.
Kleman, B. 1956, *Ap. J* , **123**, 162.
Lee, O J., Baldwin, R. B , Hamlin, D. W., and Kinnaird, R. F 1940, *Dearborn Ann* , **4**, Pt. 16.
Lee, O. J , Gore, G. D , and Bartlett, T. J. 1947, *Dearborn Ann* , **5**, Pt. 7.
Mayall, M. W. 1951, *Harvard Bull.*, No. 920, p 32.
Morgan, W. W , Code, A. D., and Whitford, A. E. 1955, *Ap. J. Suppl.*, **2**, 41 (No. 14).
Nassau, J J., and Blanco, V. M. 1954, *Ap. J.*, **120**, 129.
———. 1957*a*, *ibid.*, **125**, 193.
———. 1957*b*, *ibid.*, p. 408.
Nassau, J J., and Stephenson, C. B. 1960, *Ap. J.*, **132**, 130.
———. 1963, *Luminous Stars in the Northern Milky Way. IV* (Hamburg-Bergedorf: Hamburger Sternwarte and Warner and Swasey Observatory).
Nassau, J. J., Stephenson, C. B., and MacConnell, D. J. 1965, *Luminous Stars in the Northern Milky Way. VI* (Hamburg-Bergedorf: Hamburger Sternwarte and Warner and Swasey Observatory).
Sanford, R. F. 1926, *Pub A.S P.*, **38**, 177.
——— 1944, *Ap. J.*, **99**, 145.
Shane, C. D. 1928, *Lick Obs. Bull.*, **13**, 125.