:ev. Mexicana Astron. Astrof., 6, 83-93 (1981)

A DEEP NEAR INFRARED OBJECTIVE PRISM SURVEY FOR CARBON STARS TOWARD THE GALACTIC CENTER AND ANTICENTER

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RESUMEN

La distribución asimétrica de las estrellas de carbono frías y relativamente brillantes a lo largo del ecuador galáctico, se conoce desde hace tiempo, especialmente a través de sondeos de prisma objetivo. Para estudiar este problema cuando se incluye una muestra de estrellas mucho más débiles, se ha llevado a cabo un sondeo profundo de estrellas de carbono hacia el centro y anticentro galácticos, utilizando la técnica de prisma objetivo a muy baja dispersión. Cada región estudiada comprende un área de 322 grados cuadrados y fue observada con telescopios tipo Schmidt, de similar diseño óptico, localizados uno en el hemisferio norte y otro en el sur. Asimismo se aplicaron las mismas técnicas de observación, de identificación y de reducción de datos, haciendo de este modo ambos sondeos comparables estadísticamente. La magnitud límite hasta la cual fue posible identificar estrellas de carbono es $I = 13$.

Se presenta un catálogo que contiene las 283 estrellas de carbono observadas, 123 de las cuales representan nuevas identificaciones. Se realizó un análisis estadístico de la distribución superficial y espacial de la muestra de estrellas observadas, llegándose a los siguientes resultados:

1) El número de estrellas de carbono observado hacia el anticentro galáctico es tres veces mayor que el observado hacia el centro galáctico. 2) La asimetría centro-anticentro en la distribución parece ser real y se extiende hasta una distancia aproximada de 8 kpc. 3) Las estrellas de carbono en la muestra se concentran en tres posiciones localizadas a distancias promedio de 5.5 kpc hacia el centro galáctico y a 0.5 y 5.0 kpc hacia el anticentro, medidas desde el sol. La densidad media de estrellas de carbono en estas posiciones es de 15, 20 y 50 estrellas por kpc cúbico, respectivamente.

Los resultados obtenidos en esta investigación se han combinado con aquellos de otros autores para describir el problema global de la distribución de las estrellas de carbono en la Vía Láctea. Existe evidencia de un incremento radial del número de estrellas de carbono desde una distancia de 2 kpc del centro galáctico hacia afuera. Existe una correlación significativa entre la concentración de las estrellas de carbono y la estructura espiral de la Galaxia.

ABSTRACT

The asymmetric distribution of the cool carbon stars in the Milky Way has been known for some time, mainly from the results of objetive-prism surveys. In order to make an assessment of this problem when a fainter sample of stars is included, a deep near infrared objetive-prism survey for carbon stars has been carried out in the direction of both the galactic center and the galactic anticenter. Each survey area of 322 square degrees was observed with similar Schmidt type telescopes located in the northern and the southern hemispheres. The same observational procedures and the same identification and reduction technique were applied throughout thus making both surveys statistically comparable. The limiting magnitude to which carbon stars could be identified is $I = 13.0$.

A catalogue containing 283 carbon stars is presented, of which 123 have not been previously reported. A statistical analysis of the surface and space distribution of the stars in the sample has been carried out yielding the following results: 1) The number of carbon stars observed toward the galactic anticenter is larger than that observed toward the center by a factor of 3. 2) The center-anticenter asymmetry appears to be real and it seems to reach up to an approximate distance of 8 kpc. 3) The carbon stars in the sample appear to be concentrated at average distances from the sun of 5.5 kpc toward the galactic center, and 0.5 and 5.0 kpc toward the anticenter. The mean space density of carbon stars at these locations is 15, 20 and 50 stars per cubic kpc, respectively.

The results are combined with those obtained in other investigations to discuss the distribution of carbon stars on the galactic plane. There is evidence for an increase in the population of carbon stars

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from a distance of about 2 kpc from the center outwards. The correlation between the location where the cooler carbon stars appear to be concentrated and the spiral structure of our Galaxy seems to be significant.

Key words: STARS-CARBON – GALAXIES-MILKY WAY

I. INTRODUCTION

The study of the surface and space distribution of carbon stars, and of other late-type stars, in our Galaxy, is relevant to the theory of stellar structure and evolution, and to the understanding of galactic structure.

Most of the known carbon stars have been discovered by means of objective-prism techniques, especially the near-infrared and red techniques developed by Nassau, Blanco, and collaborators at the Warner and Swasey Observatory. The infrared techniques allow the identification of the (often cooler) carbon stars of type N, on infrared-sensitive emulsion at the very low dispersions of 1700 and 3400 A/mm (Nassau and Velghe 1964).

Early surveys of carbon stars showed that they are generally located at low galactic latitudes and continuously distributed in galactic longitude. Thereafter, a number of general and regional infrared objective-prism surveys, covering the whole Milky Way, have been carried. out by observers in both the northern and southern hemispheres. These surveys were intended to identify stars of spectral types M, carbon, and sometimes S, and their general limiting infrared magnitude was about 9.5. A list of papers dealing with the carbon stars found in these surveys has been given by Stephenson (1966). Details on all important surveys, and references to others of relative interest, that have been made up to 1970 have been given by Mavridis (1971).

A first study on the distribution of carbon stars in the Milky Way was made by Blanco (1965). Plots of their distribution with galactic longitude show that carbon stars tend to avoid that part of the Milky Way toward the galactic center and to favor the region of the galactic anticenter.

The aim of this investigation is to make a deep near-infrared objective-prism survey of carbon stars in the direction of both the galactic center and anticenter, in order to determine whether the asymmetry just mentioned is local or if it is present on a relatively large scale. I planned to extend the search of carbon stars down to about infrared magnitude $I = 13$, a fainter limit than $I = 9$ reached by most previous surveys.

In order to make both surveys statistically comparable, I carried out the observations using similar Schmidt-type telescopes and prisms, located in the northern and the southern hemispheres. Likewise, the same kind of photographic emulsion was used, and the same observational and reduction techniques were applied throughout.

The results of this study will be discussed and compared to those of other deep infrared surveys of the Milky Way carried out in recent years.

II. OBSERVATIONS

The 61/91-cm University of Michigan Curtis Sc midt-type telescope of the Cerro Tololo Inter-Americ Observatory was used on July 1978 to obtain tl objective prism plate material for a region surroundi the galactic center. In the same way, the 61/91-c Burrell Schmidt at the Nassau Station of the Warner a Swasey Observatory, of almost identical design, was us from October 1978 through April 1979 to secure tl corresponding observational material for a region su rounding the galactic anticenter. Each survey area w covered photographically by a fifteen-field plate array about 322 square degrees. The general shape of each ar is that of a cross oriented parallel to the galactic syste and extended to about $\pm 20^\circ$ in longitude and $\pm 10^\circ$ latitude.

A four-degree prism was attached to each telescop I-N Kodak emulsion was exposed through a 3 mm Scho RG8 filter. This prism-filter combination yields a ban pass between 6800 and 8800 A, with a dispersion the atmospheric A band of 1700 A mm^{-1}. The plat were exposed for 45 minutes, with the emulsi hypersensitized in a bath of distilled water at 5°C for minutes and then dried in a strong flow of cool air f 10 minutes. All exposures were guided and the spect unwidened. This procedure results in a limiting infrar magnitude of 13.0.

Carbon stars are identified on infrared-sensitive spe tral plates by the presence of the CN molecule absor tion band system at λλ7945, 8025, and 8320 (Nassau and Velghe 1964). No attempt was made classify the carbon stars found in the present survey in subclasses. This has been proven to be unfruitful at tl low dispersion involved (Stephenson 1979).

Photographic infrared magnitudes in the Kron system (Kron *et al.* 1953) were obtained for all carb stars identified in this survey. Apparent magnitudes we estimated on I-N direct plates, taken with the san telescope, with untreated emulsion, exposed for minutes through a RG8 filter. Faint *UBV* propert converted into the *VI* system, established by Hoag *et a* (1961) in the open clusters NGC 6531 and NGC 209 were transferred via plate overlapping to all the surv fields.

Positions for the carbon stars observed in this surv were obtained from either direct plates or objectiv prism plates. The plates were measured in the tw coordinate machine of the Warner and Swasey Obse vatory. The mean error in the determination of tl position of a star in a direct plate is 1 arc sec in bo coordinates.

The *General Catalogue of Cool Stars* (Stephenson 73) was used as the primary source of information for ꞓ identification procedure. The *Merged Infrared Cata- ʒue* (Schmitz *et al.* 1978) and the data file maintained · W. P. Bidelman at the Warner and Swasey Observa- ry were also consulted.

III. THE CATALOGUE

A list of the carbon stars observed toward the galactic nter and the anticenter survey areas is given in the rm of a catalogue in Table 1. The information esented here has been obtained from the observations d reduction procedures described in the preceding ction. The content of each column is the following:

Column 1:	The sequence star number in the present survey. An asterisk indicates that a note is to be found at the end of the table.
Column 2-3:	Equatorial coordinates for the mean equinox of 1900.
Column 4-5:	Galactic coordinates l and b.
Column 6:	Photographic infrared magnitude I.
Column 7:	Catalogue number as given by Stephenson (1973).

TABLE 1

THE CATALOGUE OF THE OBSERVED CARBON STARS

Num	R. A.	Dec.	l	b	I	CCCS
1	4 55 20.0	+24 9 47	178.3	-10.8	10.8	
2	55 41.2	41 48 19	164.4	+ 0.1	9.4	278
3	56 3.8	42 9 50	164.1	+ 0.4	9.8	279
4	59 34.2	40 1 51	166.2	- 0.4	9.2	283
5	5 00 31.8	40 10 35	166.2	- 0.1	10.8	
6	5 1 38.5	+40 18 56	166.2	+ 0.1	9.9	287
7	2 13.1	38 52 18	167.4	- 0.7	5.0	288
8	2 39.5	39 52 11	167.7	0.0	12.8	
9	2 45.6	40 36 38	166.1	+ 0.5	12.8	
10	3 22.7	39 15 38	167.3	- 0.3	8.6	293
11	5 3 24.9	+39 41 43	166.9	0.0	9.6	292
12	3 34.0	38 55 53	167.5	- 0.4	10.7	
13	6 2.1	40 48 7	166.3	+ 1.1	10.8	300
14	7 28.5	34 40 52	171.4	- 2.4	10.0	303
15	7 38.1	41 17 18	166.1	+ 1.6	10.6	304
16	5 7 54.1	+40 43 57	166.6	+ 1.3	9.8	305
17	8 29.4	21 11 10	182.6	-10.1	9.6	
18	9 18.8	35 27 49	171.0	- 1.6	11.6	
19	9 24.1	23 53 22	180.4	- 8.3	10.8	
20	9 47.1	36 57 26	169.9	- 0.6	10.3	306
21	5 10 52.8	+27 35 3	177.6	- 5.9	8.9	309
22	11 24.1	32 6 10	174.0	- 3.2	11.3	310
23	11 39.1	35 8 29	171.6	- 1.4	10.8	311
* 24	12 21.1	24 27 39	180.4	- 7.5	10.3	
25	12 28.4	35 41 8	171.2	- 0.9	6.2	313
26	5 12 31.5	+42 57 41	165.3	+ 3.3	11.2	
27	13 43.6	42 31 5	165.8	+ 3.2	9.7	314
28	14 31.2	37 59 17	169.6	+ 0.7	9.0	317
29	15 17.9	32 24 39	174.2	- 2.4	4.5	318
30	15 31.1	38 45 15	169.1	+ 1.3	10.8	
31	5 16 37.8	+32 22 37	174.4	- 2.1	12.2	323
* 32	16 38.8	29 18 27	176.9	-3.9	10.4	
33	16 59.2	35 7 17	172.2	- 0.5	13.0	
* 34	17 34.6	34 27 19	172.8	- 0.8	11.6	322
35	17 52.5	29 5 49	177.3	- 3.8	10.9	
36	5 17 53.9	+30 26 23	176.2	- 3.0	9.4	325
37	17 58.0	39 58 24	168.3	+ 2.4	11.2:	326
38	18 26.0	33 43 55	173.5	- 1.1	9.0	327
39	18 30.8	42 40 50	166.2	+ 4.1	10.8	
40	18 41.2	39 47 4	168.6	+ 2.4	7.1	328
41	5 18 52.7	+39 38 59	168.7	+ 2.4	11.4	
42	19 1.7	36 14 53	171.5	+ 0.5	11.8	
* 43	19 12.4	26 48 38	179.3	- 4.9	10.8	
44	19 19.6	38 17 15	169.9	+ 1.7	7.8	330
45	19 39.2	32 19 24	174.8	- 1.7	10.3	332
46	5 20 10.7	+23 57 38	181.8	- 6.3	8.5	334
47	20 15.2	31 55 20	175.2	- 1.8	9.3	333
48	20 16.2	36 42 18	171.3	+ 0.9	10.3	335
49	20 30.6	34 3 44	173.5	- 0.5	6.8	336
50	20 33.9	37 59 17	170.3	+ 1.7	9.4	337
51	5 21 25.2	+34 25 7	173.3	- 0.2	12.1:	338
52	21 27.9	37 8 14	171.1	+ 1.4	11.2	
53	21 45.1	35 24 40	172.5	+ 0.5	12.2	339
54	21 49.9	30 30 25	176.6	- 2.3	12.9	
55	22 18.6	34 25 50	173.4	0.0	12.1	341
56	5 22 20.3	+33 59 24	173.8	- 0.2	12.1	342
57	22 41.4	39 4 23	169.6	+ 2.7	10.4	
58	23 28.6	35 20 20	172.8	+ 0.7	11.5	
59	23 43.2	37 40 0	170.9	+ 2.0	10.3	
60	23 44.2	31 54 48	175.6	- 1.2	12.6	343
61	5 24 1.8	+31 38 39	175.9	- 1.3	10.8	345
62	24 18.4	26 57 27	179.8	- 3.8	10.2	
63	24 30.9	34 35 12	173.5	+ 0.5	9.1	346
64	24 37.6	31 49 36	175.8	- 1.1	9.8	347
65	25 25.9	28 12 11	178.9	- 2.9	9.5	348
66	5 25 32.6	+23 28 33	182.9	- 5.5	9.8	349
67	25 48.0	29 28 00	177.9	- 2.2	9.4	350
68	26 31.3	38 33 41	170.4	+ 2.9	10.3	
* 69	25 57.3	35 35 6	172.9	+ 1.3	10.1	354
70	26 6.2	29 36 24	177.8	- 2.0	9.4	356
71	5 26 7.5	+32 51 55	175.1	- 0.2	9.2	355
72	26 17.0	28 25 28	178.8	- 2.7	10.3	353
73	26 40.9	32 6 49	175.8	- 0.5	11.3	359
74	26 46.8	32 9 56	175.9	- 0.3	12.0	
75	26 57.0	29 33 47	178.0	- 1.9	11.5	
76	5 27 24.4	+33 15 53	174.9	+ 0.2	10.8	362
77	27 46.4	26 2 36	181.0	- 3.7	12.2	
78	28 16.7	24 47 1	182.1	- 4.3	7.3	366
79	28 25.2	33 45 52	174.6	+ 0.7	10.1	367
80	28 41.0	30 52 19	177.1	- 0.9	11.2	
81	5 30 15.6	+35 24 48	173.5	+ 1.9	13.2	
82	30 16.7	25 47 39	181.5	- 3.4	10.3	
83	31 22.1	30 0 8	178.1	- 0.9	9.2	372
84	32 10.5	22 45 34	184.3	- 4.6	7.9	374
85	32 29.0	30 23 21	177.9	- 0.5	10.2	376
86	5 33 24.3	+33 23 18	175.5	+ 1.3	9.3	377
87	33 48.9	23 6 37	184.2	- 4.1	12.2	
88	34 0.3	26 28 20	181.4	- 2.3	13.5	
89	34 0.7	34 35 37	174.5	+ 2.1	12.5	
90	34 22.1	34 34 0	174.6	+ 2.1	10.0	379

TABLE 1

(CONTINUED)

Num	R. A.	Dec.	l	b	I	CCCS
91	5 34 32.3	+27 33 1	18.6	- 1.6	11.2	
92	35 12.6	34 32 15	174.8	+ 2.3	12.0	
93	35 47.7	22 24 4	185.1	- 4.1	10.3	
94	35 56.1	28 14 21	180.2	- 1.0	10.6	382
95	36 26.5	33 37 39	175.7	+ 2.0	9.8	383
96	5 36 49.7	+31 55 13	177.2	+ 1.2	11.0	
97	37 1.8	22 44 19	184.9	- 3.7	10.4	
98	37 20.6	29 6 37	179.6	- 0.3	12.4	
99	38 34.9	30 42 55	178.4	- 0.8	12.0	
100	39 5.9	24 22 37	183.8	- 2.4	5.0	390
101	5 39 37.5	+25 27 13	183.0	- 1.8	9.3	392
102	40 02.1	25 40 51	182.9	- 1.5	10.0	
103	40 23.7	25 35 44	182.9	- 1.5	9.4	397
104	40 27.4	22 45 4	185.4	- 3.0	10.8	
105	40 39.4	23 49 8	180.2	+ 0.2	11.5	399
106	5 40 45.9	+24 9 53	184.2	- 2.2	10.3	
107	41 24.5	30 32 40	178.8	+ 1.3	9.4	401
108	41 26.5	28 41 37	180.4	- 0.3	10.6	
109	41 32.2	32 1 6	177.6	+ 2.1	10.8	
110	41 42.0	30 35 41	178.8	+ 1.3	5.0	402
111	5 41 45.8	+31 19 26	178.2	+ 1.7	11.6	
112	42 33.7	26 11 11	182.7	- 0.8	9.9	406
113	42 34.8	32 00 49	177.7	+ 2.2	10.9	405
114	43 17.4	35 43 26	174.6	+ 4.3	8.9	407
* 115	43 18.2	34 35 27	175.6	+ 3.7	10.3	
116	5 43 29.8	+23 20 53	185.2	- 2.1	10.2	
117	43 50.1	25 15 16	183.6	- 1.1	9.4	410
118	43 58.4	22 14 20	186.2	- 2.6	9.8	412
119	45 17.8	30 43 20	179.1	+ 2.1	10.9	
120	45 28.7	23 35 31	185.2	- 1.6	11.4	
121	5 45 55.0	+29 30 43	180.2	+ 1.6	11.2	
122	46 9.1	32 10 17	178.0	+ 3.0	9.4	414
123	46 22.6	29 52 54	180.0	+ 1.8	7.3	415
124	46 29.1	29 48 48	180.0	+ 1.8	10.1	416
125	46 30.3	25 19 54	183.9	- 0.5	12.8	
126	5 46 38.0	+30 37 9	179.4	+ 2.3	9.5	417
127	46 49.4	29 3 18	180.7	+ 1.0	11.6	
128	47 33.0	24 25 17	184.8	- 0.8	11.8	
129	47 40.9	22 14 21	186.7	- 1.9	10.8	
130	47 46.3	28 37 30	181.2	+ 1.4	9.4	418
131	5 47 54.4	+24 8 40	185.1	- 0.8	12.2	
132	48 14.2	30 10 20	179.9	+ 2.3	10.7	419
133	48 35.6	31 26 41	178.9	+ 3.0	9.9	421
134	48 35.9	34 1 42	176.6	+ 4.4	9.1	420
135	49 24.3	32 01 18	178.5	+ 3.5	9.6	423
136	5 49 36.7	+33 51 33	176.9	+ 4.5	9.0	424
137	49 52.5	22 50 53	186.4	- 1.1	11.6	
138	50 12.9	28 47 41	181.3	+ 2.0	10.8	
139	50 21.3	30 49 15	179.6	+ 3.0	11.5:	
140	50 26.1	30 6 3	180.2	+ 2.7	9.4	425
141	5 50 49.9	+22 44 28	186.6	- 1.0	8.7	
142	50 53.1	25 43 59	184.0	+ 0.5	12.6	
143	50 57.1	22 29 59	186.8	- 1.1	10.7	
144	51 51.6	28 27 21	181.8	+ 2.1	7.5	429
145	52 3.2	32 20 42	178.5	+ 4.1	10.8	
*146	5 52 23.1	+34 59 37	176.2	+ 5.5	12.2	
147	52 43.3	26 48 7	183.3	+ 1.4	11.9	
148	52 54.9	22 4 48	187.4	- 0.9	12.4	
149	53 41.1	24 47 24	185.2	+ 0.6	11.6	432
150	54 25.3	30 45 3	180.1	+ 3.8	9.5	434
*151	5 54 33.3	+20 51 29	188.7	- 1.2	10.3	
152	54 53.0	18 59 8	190.3	- 2.1	12.8	
153	55 1.9	21 5 5	188.5	- 1.0	9.0	435
154	55 12.6	27 39 59	182.9	+ 2.4	11.9	
155	55 17.9	21 20 47	188.3	- 0.8	12.2	
156	5 55 20.8	+29 27 2	181.3	+ 3.3	7.5	436
157	55 34.1	24 33 47	185.6	+ 0.9	12.2	
*158	55 36.0	20 11 41	189.4	- 1.3	9.7	
159	55 51.6	27 31 21	183.1	+ 2.4	7.9	439
160	56 22.5	29 38 39	181.3	+ 3.6	9.8	441
161	5 56 52.0	+24 6 21	186.1	+ 0.9	11.7	
162	57 19.1	26 0 1	184.5	+ 1.9	8.8	443
163	57 42.6	20 7 9	189.7	- 0.9	11.5	
164	57 45.3	26 52 30	183.8	+ 2.5	9.6	440
165	57 50.7	19 56 16	189.8	- 1.0	10.7	
166	5 57 51.1	+19 3 15	190.6	- 1.4	10.3	
167	59 30.5	18 31 46	191.3	- 1.4	8.8	448
168	6 0 45.1	29 12 47	182.1	+ 4.2	11.9	
169	1 9.1	22 52 33	187.7	+ 1.1	12.8	
170	2 14.2	22 43 15	187.9	+ 1.3	9.0	456
171	6 2 45.3	+19 55 10	190.4	- 0.0	10.8	
172	3 4.6	18 41 7	191.5	- 0.5	11.7	
173	3 21.3	30 2 43	181.7	+ 5.1	9.8	457
174	3 47.1	32 4 11	179.9	+ 6.2	9.8	458
175	3 49.2	19 10 25	191.2	- 0.2	12.2	
176	6 4 4.4	+19 32 57	190.9	+ 0.1	12.1	
177	4 25.1	30 38 46	181.3	+ 5.6	9.3	460
178	4 36.2	16 2 44	194.0	- 1.5	11.9	
179	4 40.4	26 1 59	185.3	+ 3.4	5.0	461
180	5 2.2	28 33 24	183.2	+ 4.7	12.5	
181	6 5 34.2	+19 42 52	190.9	+ 0.5	12.8	
182	6 23.9	20 3 32	190.7	+ 0.8	12.6	
183	6 27.0	27 40 58	184.1	+ 4.5	10.4	466
184	7 47.8	21 37 39	189.5	+ 1.9	12.2	
185	7 48.0:	13 47 00:	196.4	- 2.0	11.9	
* 186	6 8 4.9	+33 26 32	179.2	+ 7.6	10.1	
187	8 34.6	21 36 47	189.6	+ 2.0	10.8	
188	8 51.1	22 44 53	188.7	+ 2.6	10.2	
189	9 24.5	21 35 36	189.7	+ 2.2	10.2	
190	9 31.6	21 9 54	190.1	+ 2.0	9.2	468
191	6 9 36.9	+21 53 9	189.5	+ 2.4	8.9	469
192	9 37.4	21 51 59	189.5	+ 2.3	11.5	
193	9 44.8	22 25 20	189.1	+ 2.6	8.6	470
194	9 45.1	14 40 9	195.8	- 1.1	10.3	
195	9 56.8	22 51 19	188.7	+ 2.9	11.5	
196	6 11 36.8	+20 8 24	191.3	+ 1.9	10.0	478
197	11 43.1	18 38 7	192.6	+ 1.2	9.3	477
198	11 43.2	34 40 25	178.4	+ 8.8	12.3	
199	11 59.8	14 31 1	196.2	- 0.7	7.6	479
200	12 38.0	15 20 28	195.6	- 0.2	10.8	
201	6 12 56.2	+20 10 56	191.4	+ 2.2	8.4	483
202	13 15.0	21 39 28	190.1	+ 3.0	8.8	485
203	13 52.2	18 17 46	193.1	+ 1.5	9.5	488
204	15 19.2	16 18 36	195.0	+ 0.8	10.3	
205	16 29.7	14 28 9	196.8	+ 0.2	9.5	
206	6 16 50.4	+15 21 52	196.0	+ 0.7	9.8	
207	19 13.3	17 3 26	194.8	+ 2.0	12.2	
208	19 34.7	15 19 43	196.4	+ 1.3	10.0	
209	19 45.9	14 46 37	196.9	+ 1.1	5.0	508
210	19 49.5	16 8 44	195.7	+ 1.7	11.4	
211	6 20 54.6	+18 29 57	193.8	+ 3.1	12.2	
212	21 34.4	15 50 14	196.2	+ 1.9	10.8	516
213	23 2.5	16 53 24	195.4	+ 2.7	10.9	
214	23 6.1	35 45 15	178.5	+11.4	8.5	
215	25 53.9:	16 11 00:	196.4	+ 3.0	8.0:	523
216	6 27 06.0:	+16 33 30:	196.2	+ 3.5	11.5	
* 217	16 53 8.2	-24 18 30	357.9	+11.1	11.4	
218	16 53 24.8	-21 13 13	0.4	+12.9	11.5	
* 219	16 53 44.8	-24 12 5	358.0	+11.0	10.5	
220	16 55 36.7	-41 0 47	345.0	+ 0.4	11.7	
221	17 1 54.8	-43 38 30	343.6	- 2.2	11.2:	2398
222	4 7.8	40 18 33	346.5	- 0.5	12.7	2403
223	5 38.1	39 24 57	347.4	- 0.2	12.6	2404
224	6 59.3	35 48 11	350.5	+ 1.8	8.8	2409
225	7 37.1	42 7 21	345.5	- 2.1	9.5	2411
226	17 10 37.3	-35 21 44	351.2	+ 1.4	12.2	2418
227	11 53.5	38 4 9	349.2	- 0.4	10.8	2423
228	13 47.2	40 17 0	347.6	- 2.0	7.2	2429
229	14 30.1	40 22 44	347.6	- 2.1	11.0	
230	15 27.0	36 40 1	350.8	- 0.1	10.0	2431
231	17 17 10.9	-40 7 53	348.1	- 2.4	9.5	2435
232	17 24.7	28 15 1	357.9	+ 4.4	8.8	2436
233	17 39.4	29 13 50	357.1	+ 3.8	6.5	2438
234	17 42.8	39 3 44	349.1	- 1.9	12.0:	
235	18 42.5	29 39 45	356.9	+ 3.4	10.2	2439
236	17 19 20.6	-31 45 20	355.2	+ 2.0	12.0	
237	19 24.5	32 20 6	354.8	+ 1.7	12.0:	2441
238	20 6.8	31 29 59	355.5	+ 2.0	11.1	2443
239	20 6.9	39 19 19	349.1	- 2.4	11.5	2444
240	22 55.0	30 51 7	356.4	+ 1.9	12.0	

TABLE 1

(CONTINUED)

Num	R. A.	Dec.	l	b	I	CCCS
241	17 25 5.1	-35 11 58	353.1	- 0.9	12.0	
242	26 48.4	34 28 18	353.9	- 0.8	10.0	2454
243	26 52.5	36 11 5	352.5	- 1.7	9.0	2455
244	27 59.6	34 6 36	354.3	- 0.8	10.5	2458
245	28 9.8	32 53 43	355.3	- 0.2	12.5	
246	17 29 7.4	-33 38 56	354.9	- 0.7	10.0	2459
247	29 40.4	34 32 42	354.1	- 1.3	10.0	2461
248	32 11.0	28 41 39	359.3	+ 1.4	10.5	2463
249	35 41.7	35 11 41	354.3	- 2.7	8.0	2473
250	35 44.6	32 8 18	356.8	- 1.1	11.5	
251	17 38 52.0	-26 50 51	1.7	+ 1.2	12.5	
252	43 32.9	27 26 33	1.7	0.0	12.2	
253	46 55.0	28 48 35	0.9	- 1.4	10.0	2490
254	47 17.5	23 15 21	5.7	+ 1.4	10.0	2491
* 255	48 41.8	32 3 3	358.4	- 3.4	9.6	
256	17 48 55.9	-27 57 34	1.9	- 1.3	10.8	
257	49 13.7	27 9 44	2.6	- 1.0	11.3	2496
258	49 29.8	25 26 49	4.1	- 0.1	11.0	2498
259	49 38.0	28 0 49	1.9	- 1.5	7.0	2499
260	50 20.0	23 12 22	6.1	+ 0.9	9.5	2500
261	17 50 51.4	-24 5 20	5.4	+ 0.3	12.2	
262	51 7.1	23 27 18	6.0	+ 0.6	10.5	2503
263	53 4.7	30 27 24	0.2	- 3.4	11.4	
264	53 36.3	27 34 43	2.8	- 2.0	11.7	
265	53 45.9	31 3 16	359.8	- 3.8	10.4	
266	17 54 28.8	-33 53 28	357.4	- 5.3	10.3	
267	54 41.3	29 5 11	1.6	- 3.0	9.0	2511
268	56 20.3	24 45 58	5.5	- 1.1	11.3	2520
269	56 34.4	19 10 22	10.4	+ 1.6	6.6	2521
270	57 21.2	32 13 20	359.1	- 5.0	10.1	
271	18 0 42.3	-19 8 23	10.9	+ 0.8	13.3:	
272	0 53.9	33 17 9	358.6	- 6.2	10.2	
273	1 8.8	28 31 15	2.8	- 3.9	8.0	2529
274	3 2.5	27 39 39	3.7	- 3.9	9.0	2535
275	3 28.2	21 40 41	9.0	- 1.0	9.3	2537
276	18 4 5.4	-32 39 10	359.5	- 6.5	9.5	
277	4 12.8	26 53 1	4.5	- 3.7	9.2	2540
278	08 06.0:	14 54 12:	15.4	+ 1.4	8.5	2551
279	10 12.4	16 30 52	14.3	+ 0.1	8.9	2554
280	10 42.9	20 36 58	10.7	- 2.0	12.8	
281	18 11 16.1	-21 56 50	9.6	- 2.7	12.5	
282	13 37.1	15 39 10	15.4	- 0.2	6.2	2567
283	16 17.0	19 3 55	12.7	- 2.4	9.2	2569

(*) Notes to Table 1

24 BC 63
32 BC 64
34 CCCS position $1^{\mathrm{m}}.0$ off in R A.
43 BC 65
69 BC 11
115 BC 13
146 BC 15
151 BC 34
158 BC 36
186 BC 71
192 Fainter visual companion of 191. Separation $\sim 1'.5$, $\Delta I = 2.5$.
217 McC 79
219 McC 79
255 McC 79

Sources of Information

Symbol	*References*
CCCS	Stephenson 1973.
BC	Alksne and Ozolina 1972, 1974, 1976.
	Alksnis *et al.* 1976, 1979, 1978.
	Daube and Ozolina 1974.
McC	MacConnell 1979.

IV. STATISTICAL ANALYSIS

Results for the surface and space distribution of the carbon stars observed in this survey are derived below, based upon the information provided in the catalogue described in §III.

a) *Surface Density*

Surface distribution plots for all the carbon stars observed toward the galactic center and anticenter are presented in Figures 1 and 2. Comparison of these figures indicates that the number of cool carbon stars observed toward the anticenter is 3.2 times larger than the number observed toward the center.

Surface distribution plots of the fainter carbon stars, $I \geqslant 10.5$, are shown in Figures 3 and 4. Both distributions look remarkably flatter than the distribution showing all the stars in the samples. The number ratio in this case is also 3.2. These results confirm previous evidence of a center anticenter asymmetry based only upon surveys of bright carbon stars (Blanco 1965). Furthermore, they provide new evidence for an asymmetry extending to a larger distance.

Wolf diagrams showing the surface density distribution of carbon stars as a function of apparent infrared magnitude corrected for interstellar extinction were constructed (Figure 5). Values of the infrared interstellar extinction, A_I, were derived assuming a $1/\lambda$ absorption law and a ratio $A_V/A_I = 1.82$ (Sharpless 1963). The dependence of A_I with distance was then derived from photometric observations of young open clusters located close to the galactic plane (Becker and Fenkart 1971). The diagrams for the galactic center and anticenter are remarkably alike. Both distributions run almost parallel to each other for a wide range in magnitudes both show

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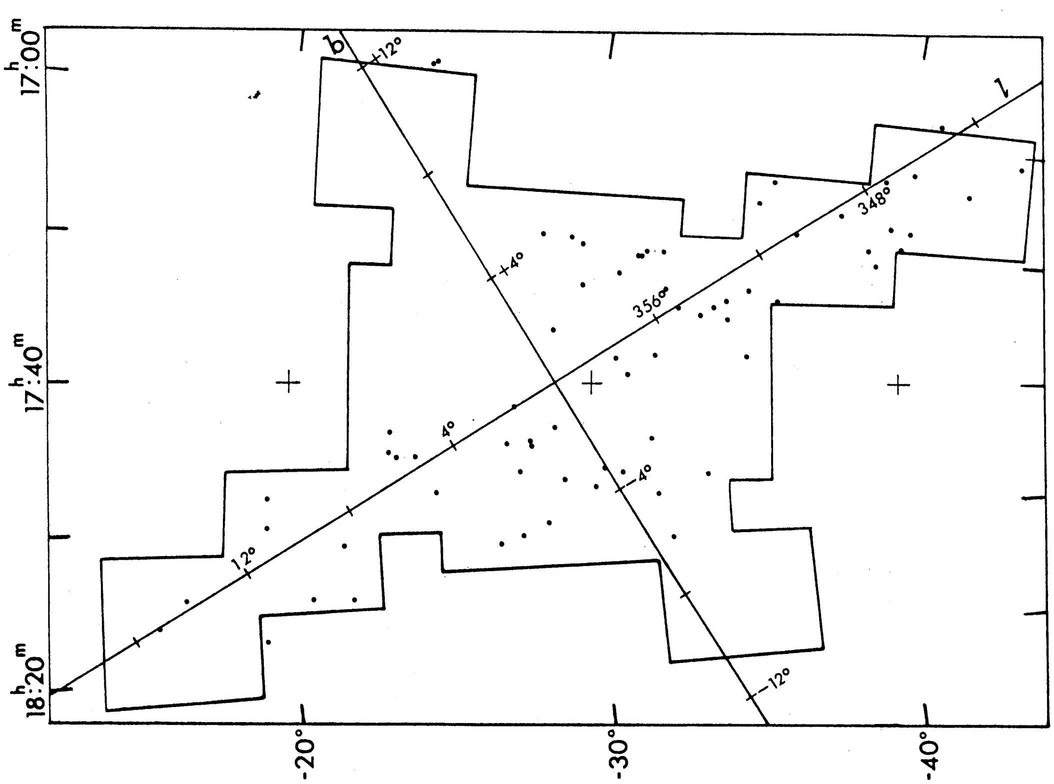

Fig. 1. The surface distribution of the carbon stars observed toward the galactic center. The outline shows the area covered by the survey. Equatorial coordinates for the mean equinox 1900 and galactic coordinates are also included in the diagram.

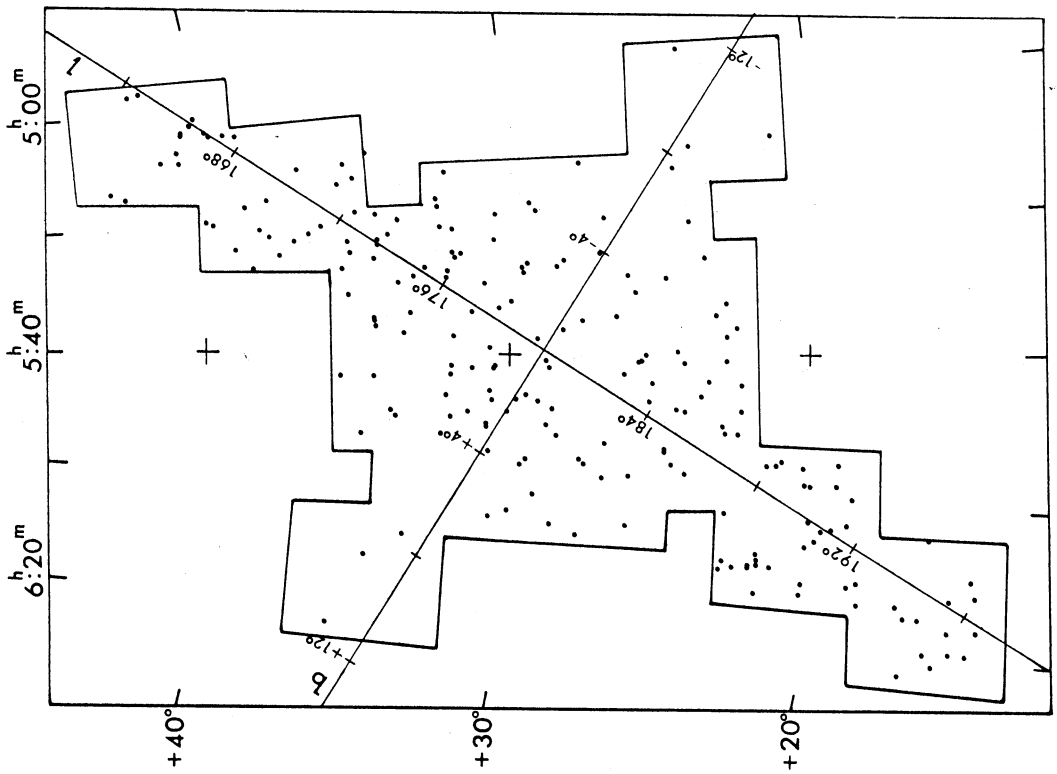

Fig. 2. The same as in Figure 1, but for the galactic anticenter.

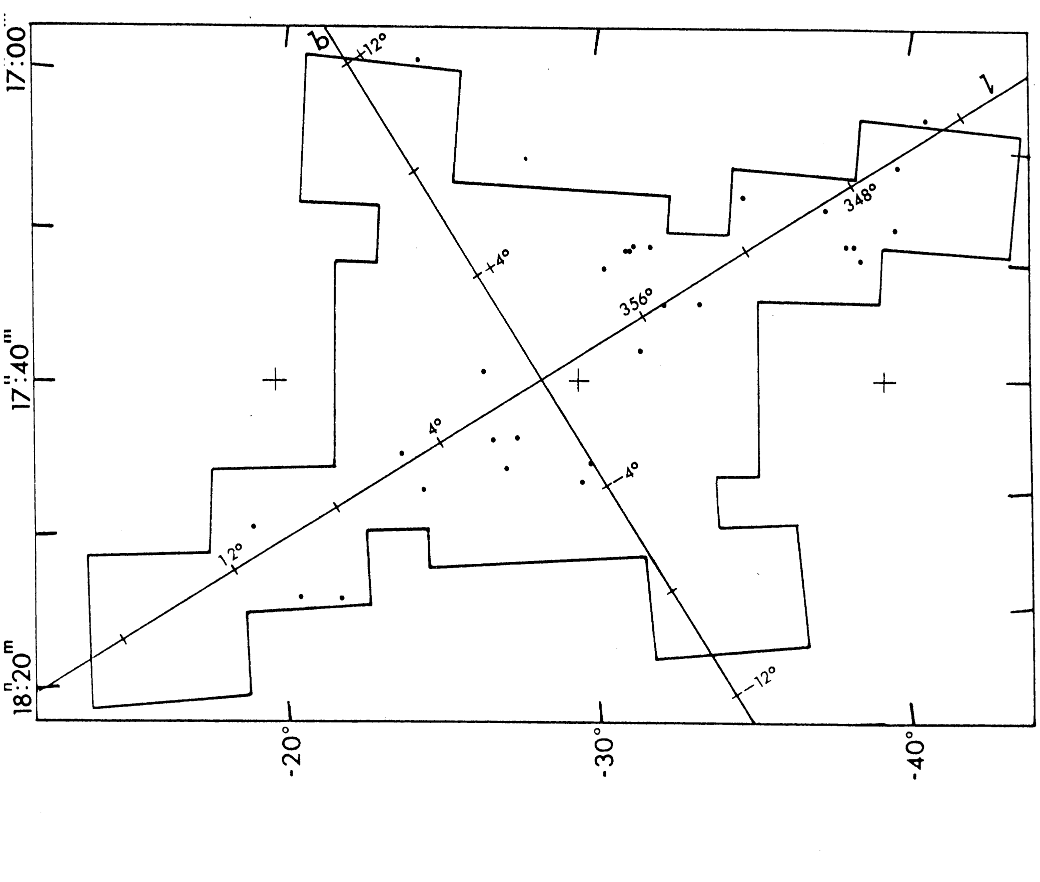

Fig. 3. The surface distribution of the carbon stars fainter than magnitude $I = 10.5$ observed toward the galactic center. The outline shows the area covered by the survey. Equatorial coordinates for the mean equinox 1900 and galactic coordinates are also included in the diagram.

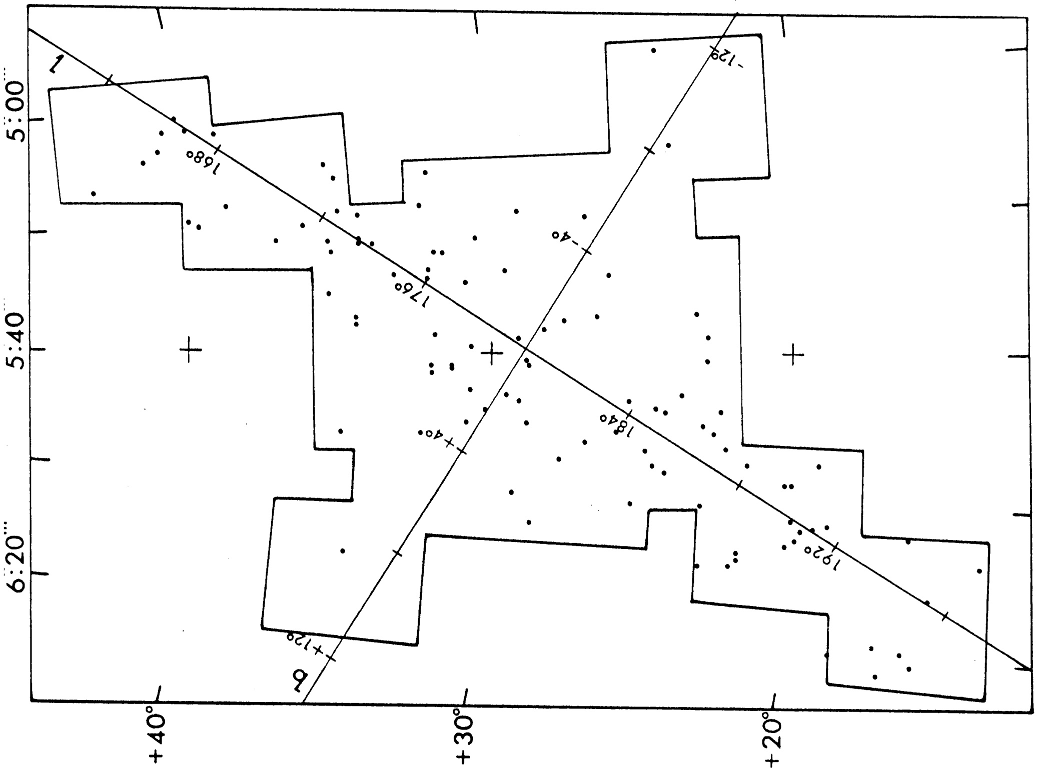

Fig. 4. The same as in Figure 3, but for the galactic anticenter.

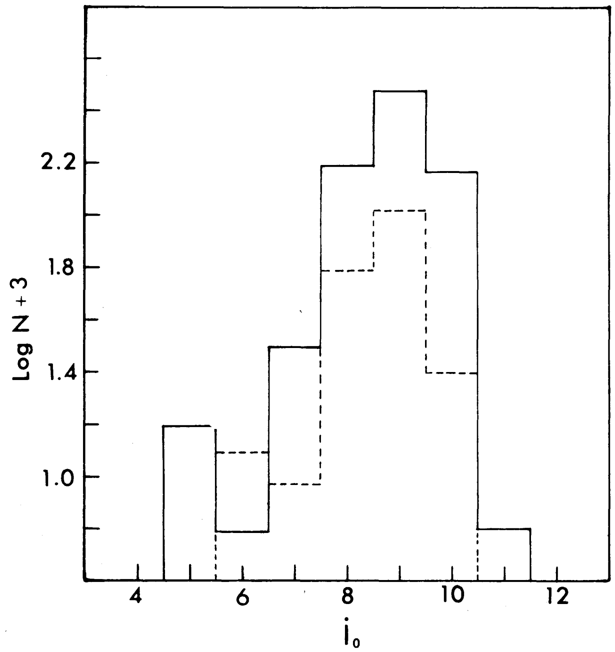

Figure 5. The Wolf diagrams for the carbon stars with apparent infrared magnitudes. I_0, corrected for interstellar absorption observed toward the galactic center survey area (dashed lines), and the galactic anticenter survey area (solid lines).

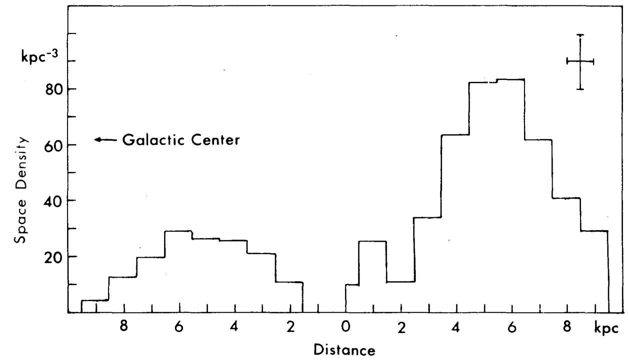

Fig. 6. The space density function for the cool carbon stars toward the galactic center and anticenter, as observed from the sun. Estimated error bars are indicated.

an excess of bright stars, and both distributions fall off a about the same value of apparent magnitude. The Wolf diagrams also show that the present survey appears to be complete up to apparent infrared magnitude 11.0.

b) *Space Density*

A space density function for carbon stars toward the galactic center and anticenter can be obtained provided an assumption is made as to the value of their mean infrared absolute magnitude. Independent determinations of the distances to several carbon stars, and recent infrared photometric observations of galactic carbon stars (Walker 1980), point to a mean value of $M_V = -2.5$ and an intrinsic color in the range $V - I \sim 2\text{-}3$. Therefore, it seems reasonable to adopt a value of $M_I = -5$ as the average infrared absolute magnitudes for these stars. The space density function was computed applying the Malmquist's method. It is given in Table 2, in units of stars kpc^{-3} and is plotted in Figure 6.

Since both objective prism surveys are statistically comparable the mean and the relative values of the space density function are meaningful. The conclusions derived from this analysis are the following:

1. The ratio anticenter-center between the mean values of the space density is 3.3, close to the ratio derived from star counts on the surface distribution plots.

2. The cool carbon stars appear to be concentrated at the average distances from the sun of 0.5 and 5.0 kpc, toward the galactic anticenter, and at 5.5 kpc toward the

TABLE 2

SPACE DENSITY FUNCTION

		Galactic Center		Galactic Anticenter	
d(kpc)	V X 10³	N X 10³	D	N X 10³	D
0.5	0.305	–	–	3.1	10.16
1.0	0.609	–	–	15.5	25.45
2.0	1.218	12.5	10.26	13.2	10.84
3.0	1.828	39.8	21.77	62.0	33.92
4.0	2.437	62.1	25.48	155.2	63.68
5.0	3.046	79.4	26.07	251.2	82.47
6.0	3.655	105.6	28.89	304.3	83.26
7.0	4.264	83.2	19.51	263.0	61.68
8.0	4.874	62.0	12.72	199.5	40.93
9.0	5.483	24.0	4.38	158.5	28.91

galactic center. The mean space density at those distances is 15, 20 and 50 stars kpc^{-3}, respectively.

V. DISCUSSION

The results for the surface and space distribution of the cool carbon stars toward the galactic center and anticenter, as presented in this study, are discussed here in the light of those obtained from several other deep surveys carried out recently in different regions of Milky Way. An up-to-date picture of the distribution of carbon stars along the galactic equator as seen from the sun is also discussed.

a) *Deep Surveys in the Milky Way*

Since 1970 several deep objective-prism surveys for carbon stars have been carried out in different regions of the Milky Way, using either red or infrared sensitive emulsions. Westerlund (1971) has made an extensive infrared survey of the southern Milky Way covering about 135 degrees in longitude. Nandy and Smriglio (1970) and Nandy, Smriglio and Buonans (1978), have carried out a series of small-area surveys in the northern Milky Way. The surveys mentioned so far have a limiting magnitude $I = 12.0$. Alksnis and Alksne (1977), and Daube and Duncans (1977) have made a series of red surveys and follow-up photometric investigations of carbon stars in several regions in the northern Milky Way. These surveys have an average limiting magnitude of $V = 14.0$ and produced identifications for about 200 new carbon stars. MacConnell (1979) has carried out a somewhat less deep survey using red-sensitive plates. This survey has a limiting magnitude of $V = 12.0$, and overlaps almost all of Westerlund's survey area, thus yielding a relatively small number of new carbon stars. Blanco *et al.* (1978), using a recently introduced non-objective-prism spectral technique (Hoag 1976), have made an exploratory infrared survey of the galactic bulge up to a limiting magnitude $I = 18.0$. Only one carbon star was detected in a small clear area around Baade's window.

A list with the characteristics of some important objective-prism surveys as known to the author, carried out recently is given in Table 3. These surveys, except for Westerlund's survey, were published at a more recent date than the Cool Carbon Stars Catalogue (Stephenson 1973).

b) *A Picture of the Distribution of Carbon Stars on the Galactic Plane*

Figure 7 summarizes the results obtained from an analysis of the infrared surveys listed in Table 3. The diagram represents the known distribution of carbon stars and shows the number of stars per 10° interval in longitude and within a belt 4° wide along the galactic equator. All numbers were normalized to the scale shown on the diagram. The original distribution as presented by Blanco (1965) is included; those are stars found in infrared objective-prism surveys.

Some conclusions may be drawn from this diagram: 1) The main features of the original distribution as given by Blanco are confirmed, and emphasized by the new results. This indicates that the center-anticenter asymmetry of the distribution of carbon stars is real, despite the influence of the interstellar absorption at the implied larger distance. 2) The observed number of carbon stars increases significantly at certain particular directions which roughly coincide with tangents to known spiral features around the Sun as traced by young open star clusters, emission stars of type OB and B, late-type supergiants, and other objects considered as spiral tracers (Moffat and Vogt 1973). This correlation is apparent at the longitudes 240° (Carina), 285° (Sagittarius), and 90° (Cygnus). On the other hand, the depletion of carbon stars in the tangential direction toward the Centaurus spiral feature at $\ell = 315°$, in the general direction toward the galactic center is noticeable.

TABLE 3

RECENT DEEP SURVEYS FOR CARBON STARS IN THE MILKY WAY

No.	Region	l	b	Area (sq dg)	No. of C Stars	Limiting Magnitude	References
1	Cygnus	88°	0°	12	26	$m_i = 12.0$	Nandy and Smriglio 1970
2	S. Milky Way	235-7°	+5°	1350	1124	$m_i = 12.0$	Westerlund 1971
3	Cygnus	90°	±9°	81	45	$V = 14.0$	Alksnis and Alksne 1977
4	Anticenter	174°	±9°	81	27	$V = 14.0$	Daube and Duncans 1977
5	Cassiopeia	118°	0°	15	20	$m_i = 12.0$	Nandy *et al.* 1978
6	Baade's Window[a]	0°	−5°	0.1	1	$I = 18.0$	Blanco *et al.* 1978
7	S. Milky Way	230-20°	±15°	4500	494	$V = 12.0$	MacConnell 1979
8	Cygnus	80-90°	−5°	48	20	$V = 16.5$	Kurtanizde and West 1980
9	G. Center	348-16°	±10°	322	67	$I = 13.0$	Present Survey
10	Anticenter	168-196°	±10°	322	216	$I = 13.0$	Present Survey

a. A non-objective-prism survey: a prism-grating combination (grism) at the prime-focus plane of a large reflecting telescope was used.

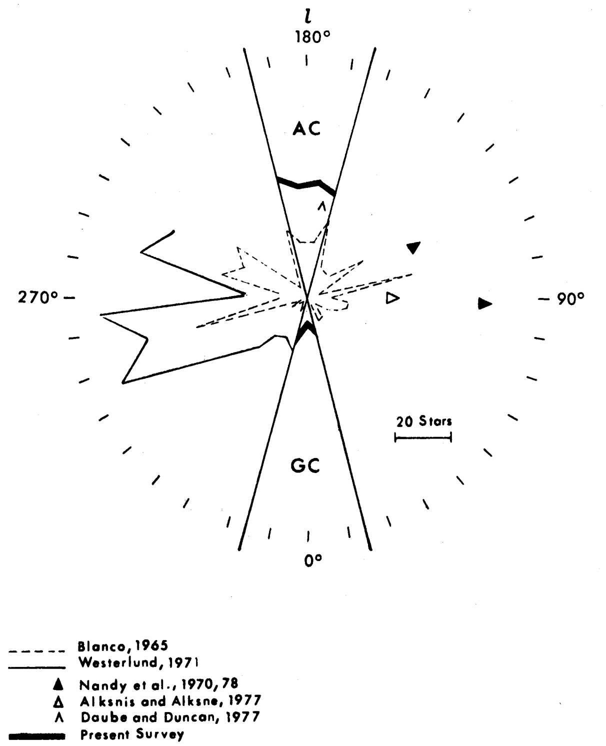

Fig. 7. Distribution of the cool carbon stars near the galactic planes as derived from infrared objective-prism surveys. The diagram shows the number of stars per 10° interval located within 2° of the galactic equator. The sources of information utilized are indicated at the lower-left side of the diagram.

3) The number of carbon stars observed toward the galactic anticenter is relatively small as compared to the number observed toward the tangential directions just mentioned. This may be interpreted as an effect arising from viewing across the main body of the outer spiral arms.

The main result of this investigation is that there is evidence of a gradual increase in the number of cool carbon stars, on the galactic plane, from a distance of about 2 kpc from the galactic center outwards. This evidence is in agreement with a radial gradient of the space density obtained for the carbon stars observed in this survey.

I would like to thank Dr. C.B. Stephenson for suggesting this research. I am also grateful to the faculty staff and students of the Warner and Swasey Observatory for their kind hospitality during my stay as a graduate student. This work was supported by a scholarship granted to me by the Universidad de Los Andes, Mérida, Venezuela.

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DISCUSSION

Sofia: ¿Did you find enough stars of spectral type S on your plates to be able to say whether they show the same asymmetries between center and anti-center as the carbon stars?

Fuenmayor: No, I did not look for S stars.

Niemela: ¿Existe entre las estrellas de carbono de las nubes de Magallanes el mismo tipo de asimetría entre el centro y periferias que en nuestra Galaxia?

Fuenmayor: Sí, Blanco y otros han encontrado resultados que apuntan en esa dirección.

Sofia: ¿Puede usted dar una explicación teórica, aunque especulativa, de la razón por la cual estrellas de carbono trazan los brazos espirales?

Fuenmayor: La tasa de formación de estrellas de carbono puede estar conectada con el contenido inicial de metales en el material estelar primigenio.

Mendoza E.: Deseo comentar que se podría llegar a magnitudes más débiles en el descubrimiento de estrellas de carbono, combinando la cámara Schmidt con filtros UV e IR, ya que estas estrellas tienen una fuerte deficiencia en el UV y un exceso infrarrojo.

Francisco Fuenmayor: Departamento de Física, Facultad de Ciencias, Universidad de Los Andes, Mérida, Venezuela.