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HIGH-LUMINOSITY CARBON STARS IN THE GALACTIC ANTICENTER

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ABSTRACT

We report K-band magnitudes of a sample of 211 carbon stars in the Galactic anticenter. Using the assumptions that carbon stars have a narrow range in K-band luminosity and $(I-K)$ color, we find that the surface density, range of brightness, and observed colors of stars in this sample can be understood if (1) the K-band extinction gradient in the Galactic plane near $l = 180°$ is between 0.15 and 0.3 mag kpc^{-1} and (2) the density of high-luminosity carbon stars is not significantly lower at 3 kpc from the Sun in the anticenter direction than in the solar neighborhood, in contrast to the total density of disk stars, which decreases significantly on this scale. A plausible interpretation of this increase in the relative number of high-luminosity carbon stars in the anticenter direction is that (1) the metallicity of stars in the anticenter direction is lower than in the solar neighborhood and (2) lower metallicity stars spend a longer time [perhaps $(2\text{–}3) \times 10^5$ yr] as carbon stars than do solar-metallicity stars, which may spend 10^5 yr in this stage of their evolution. The data strongly suggest that the anticenter high-luminosity carbon stars have a lower average mass-loss rate (1.2×10^{-7} $M_\odot$ yr^{-1}) than do the local carbon stars, whose average mass-loss rate is larger than this value by a factor of about 1.7.

I. INTRODUCTION

Carbon stars have high luminosities, distinctive optical spectra and red colors. They can therefore be seen to large distances from the Sun and used to study Galactic structure (Cohen *et al.* 1981).

Because they are losing large amounts of mass, carbon stars are an important source of interstellar material. By studying the stars in the anticenter direction where the metallicity is lower than in the solar neighborhood, we can hope to infer the mass-loss rate as a function of metallicity.

Fuenmayor (1981) has reported a systematic objective-prism survey (to $I = 11$ mag) of carbon stars in the plane of the Milky Way in the anticenter direction. However, attempts to deduce the spatial distribution of carbon stars from these data are complicated because the amount of circumstellar and interstellar reddening of carbon stars can be significant at this wavelength and because carbon stars display a relatively large range in their intrinsic absolute magnitude at I (1.29 mag; Claussen *et al.* 1987). To overcome these problems, we have measured the K-band magnitudes of almost all (211 out of 216) of the carbon stars identified by Fuenmayor in the anticenter region. At this wavelength, the extinction is only about 25% of that at I, and the dispersion in absolute magnitude is much lower (0.65 mag; Schechter *et al.* 1987). These K-band fluxes are used here to infer the spatial distribution of the carbon stars with the assumption that all carbon stars have nearly the same mean K-band luminosity (Frogel, Persson, and Cohen 1980).

Claussen *et al.* (1987) have used the carbon stars identified in the *Two Micron Sky Survey* (Neugebauer and Leighton 1969, hereafter TMSS) to derive the properties of carbon stars in the neighborhood ($d < 1500$ pc) of the Sun. They found that the exponential scale height of carbon stars is 200 pc and that the local space density of these stars is 100 kpc^{-3}. This value is in disagreement with the local density of carbon stars inferred by Fuenmayor (1981) of 20 kpc^{-3}. One purpose of this paper is to check this discrepancy, and to test Fuenmayor's conclusion that the space density of carbon stars increases outward from the Sun in the anticenter direction.

In this paper, we consider only the high-luminosity carbon stars that are detected in the *Two Micron Sky Survey;* we ignore the lower luminosity R-type objects.

II. OBSERVATIONS

We present K-band photometry of 211 of Fuenmayor's stars in Table 1. These data were obtained during 1987 October and November using an InSb photometer on the KPNO[2] 1.3 m telescope. To facilitate comparison with the *IRAS* data, we convert the K-band magnitudes to janskys using 620 Jy = 0.0 mag (Beckwith *et al.* 1976).

Because these stars are variable, our K-band magnitudes are not always in agreement with the results given in the TMSS; a comparison between the two sets of data is shown in Table 2. Two of these stars were noted as 2.2 μm variables in the TMSS, as indicated by their χ^2 excess. These same two stars show the greatest discrepancy between our K-band magnitudes and those in the TMSS.

The *IRAS Point Source Catalog* (1985) provides additional photometry, at wavelengths where the circumstellar dust

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[2] Kitt Peak National Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

INFRARED FLUXES FOR FUENMAYOR'S STARS

Star No.	m_I	m_K	F_ν 2 µm	F_ν 12 µm	F_ν 25 µm	F_ν 60 µm	F_ν 100 µm	Δφ "
1	10.8	4.75	7.8	1.3	<0.48	<0.40	< 1.5	2
2	9.4	5.22	5.1	0.65	<0.30	<0.40	< 1.5	13
3	9.8	5.12	5.6	1.1	<0.35	<0.40	< 1.8	17
4	9.2	4.40	10.8	2.7	0.87	0.62	< 1.3	18
5	10.8	6.45	1.6	0.74	<0.27	<0.40	< 1.5	12
6	9.9	6.12	2.2	.....	.....	.....	.....	561
7	5.0	2.31	74	17	5.1	1.4	< 9.4	2
8	12.8	6.06	2.3	6.2	2.3	0.54	< 1.4	
9	12.8	5.30	4.7	1.0	0.39	<0.40	< 1.6	15
10	8.6	4.03	15	3.0	0.73	<0.43	< 2.7	9
11	9.6	4.37	11	3.5	0.98	<0.46	< 1.6	4
12	10.7	5.56	3.7	0.64	0.28	<0.40	< 1.7	2
13	10.8	5.49	3.9	1.3	0.47	<0.40	< 6.9	5
14	10.0	5.28	4.8	1.1	<0.40	<3.4	< 7.7	26
15	10.6	6.14	2.2	0.51	<0.26	<0.46	< 2.9	2
16	9.8	5.84	2.9	0.58	<0.36	<0.40	< 8.9	19
17	9.6	5.77	3.1	0.54	<0.37	<0.40	< 7.5	18
18	11.6	6.38	1.7	0.38	<0.30	<1.5	<11	42
19	10.8	7.17	0.84	.....	.....	.....	.....	416
20	10.3	5.35	4.5	0.92	<0.37	<0.40	<13	4
21	8.9	4.26	12	3.8	1.0	<0.40	< 1.2	5
22	11.3	6.66	1.3	.....	.....	.....	.....	981
23	10.8	3.95	16	40	12	2.4	<13	28
24	10.3	5.51	3.9	0.67	<0.39	<0.40	< 2.3	4
25	6.2	2.63	55	9.3	2.7	0.75	< 3.0	3
26	11.2	5.96	2.6	0.48	<0.29	<0.40	< 1.9	4
27	9.7	4.87	7.0	1.4	0.35	<0.40	< 8.5	12
28	9.0	4.61	8.9	1.8	1.0	0.59	<12	5
29	4.5	1.87	110	69	21	3.3	< 4.3	1
30	10.8	6.12	2.2	0.91	<0.39	<0.40	<11	30
31	12.2	5.52	3.8	1.3	<0.35	<0.51	< 6.6	6
32	10.4	6.19	2.1	.....	.....	.....	.....	1126
33	13.0	7.29	0.75	0.73	<0.35	<2.0	<21	9
34	11.6	5.74	3.1	0.83	<0.50	<1.1	<13	11
35	10.9	6.74	1.2	.....	.....	.....	.....	921
36	9.4	5.44	4.1	0.49	<0.25	<0.45	< 3.3	12
37	11.2:	4.74	7.9	9.0	2.4	0.66	< 1.5	7
38	9.0	4.53	9.6	1.4	0.53	1.1	<22	7
39	10.8	5.82	2.9	0.48	<0.32	<0.40	< 2.3	4
40	7.1	5.11	5.6	0.84	0.38	<0.40	< 1.6	11
41	11.4	6.76	1.2	.....	.....	.....	.....	508
42	11.8	6.71	1.3	.....	.....	.....	.....	424
43	10.8	6.32	1.8	.....	.....	.....	.....	106
44	7.8	2.20	82	74	23	4.7	<14	3
45	10.3	5.45	4.1	0.67	<0.46	<0.40	< 2.5	2
46	8.5	3.75	20	4.6	1.2	0.53	< 1.9	4
47	9.3	5.07	5.8	0.93	<0.40	<0.40	< 4.3	17
48	10.3	5.97	2.5	1.3	0.77	<0.40	< 0.40	5
49	6.8	1.55	150	162	41	9.5	11	12
50	9.4	5.19	5.2	0.93	<0.37	<0.40	<10	2
51	12.1:	5.10	5.7	2.7	0.84	<0.20	<22	7
52	11.2	6.23	2.0	0.95	<0.32	<0.44	<13	
53	12.2	6.70	1.3	.....	.....	.....	.....	335
54	12.9	7.15	0.86	.....	.....	.....	.....	632
55	12.1	5.46	4.1	0.99	<0.38	<2.7	20	30
56	12.1	6.58	1.4	.....	.....	.....	.....	349
57	10.4	5.39	4.3	0.83	<0.31	<0.40	<14	2
58	11.5	9.44	0.10	.....	.....	.....	.....	438
59	10.3	5.07	5.8	1.8	1.6	0.78	<11	4
60	12.6	7.03	0.96	0.40	<0.31	<0.40	<3.9	14
61	10.8	5.59	3.6	0.77	<0.36	<0.40	<3.0	16
62	10.2	9.91	0.067	.....	.....	.....	.....	528
63	9.1	4.83	7.3	2.4	0.66	<1.6	<19	3
64	9.8	4.50	9.8	2.2	0.90	<0.45	< 3.8	12
65	9.5	4.91	6.7	1.1	0.37	<0.40	<11	7
66	9.8	5.86	2.8	0.42	<0.29	<0.40	< 2.1	15
67	9.4	4.73	8.0	1.6	0.59	<0.40	< 2.2	90
68	10.3	....	.....	.....	.....	.....	.....	816
69	10.1	6.10	2.3	.....	.....	.....	.....	459
70	9.4	3.87	18	4.0	1.2	<0.40	< 2.5	5
71	9.2	4.62	8.8	1.6	0.49	<0.40	< 2.8	24
72	10.3	5.48	4.0	0.57	<0.41	<0.40	<21	78
73	11.3	5.93	2.6	....	.....	.....	.....	346
74	12.0	....	....	....	.....	.....	.....	453
75	11.5	5.25	4.9	1.0	<0.29	<0.40	<11	3
76	10.8	5.70	3.3	0.81	<0.28	<0.40	< 2.1	11
77	12.2	6.85	1.1	....	.....	.....	.....	979
78	7.3	3.38	28	5.0	1.2	<0.40	< 1.8	5
79	10.1	4.38	11	2.7	0.82	<0.40	< 2.5	61
80	11.2	4.86	7.1	2.4	0.86	0.49	3.3	4

TABLE 1—*Continued*

Star No.	m_I	m_K	F_ν 2 μm	F_ν 12 μm	F_ν 25 μm	F_ν 60 μm	F_ν 100 μm	Δφ "
81	13.2	6.21	2.0	4.4	2.0	0.75	<11	7
82	10.3	5.35	4.5	1.0	<0.35	<0.40	< 2.3	8
83	9.2	3.37	28	6.8	1.9	0.73	<14	4
84	7.9	2.92	42	9.9	3.2	0.98	< 9.1	1
85	10.2	4.48	10	2.5	0.78	0.83	<12	1
86	9.3	4.33	11	3.0	0.96	<0.41	< 3.4	3
87	12.2	5.30	4.7	1.6	0.60	<0.40	<12	6
88	13.5	5.63	3.5	1.3	<0.34	<0.40	< 2.9	1
89	12.5	7.10	0.90	....	.....	.....	.....	278
90	10.0	4.57	9.2	1.6	0.52	<0.41	<16	5
91	11.2	5.48	4.0	1.2	0.53	<0.40	< 7.2	5
92	12.0	5.43	4.2	1.1	0.49	<0.57	<15	6
93	10.3	5.06	5.9	1.3	<0.61	<0.40	<11	7
94	10.6	4.53	9.6	1.9	0.65	<0.40	< 3.0	3
95	9.8	4.98	6.3	1.5	0.51	<0.40	< 3.0	3
96	11.0	5.57	3.7	0.72	<0.36	<0.40	<11	22
97	10.4	6.41	1.7	....	.....	.....	.....	566
98	12.4	7.18	0.83	....	.....	.....	.....	291
99	12.0	5.92	2.7	1.7	0.58	<0.49	3.0	3
100	5.0	1.66	134	35	9.2	2.6	< 2.2	1
101	9.3	4.20	13	2.5	1.2	2.2	< 2.2	4
102	10.0	4.63	8.7	1.8	0.64	<0.40	< 2.4	44
103	9.4	4.10	14	2.8	0.97	<0.40	<10	15
104	10.8	6.10	2.3	0.52	<0.49	<0.92	< 2.0	15
105	11.5	....	....	....	.....	.....	.....	573
106	10.3	5.92	2.7	0.43	<0.37	<0.40	< 2.7	25
107	9.4	3.97	16	3.3	0.93	<0.51	< 8.3	9
108	10.6	4.95	6.5	1.6	0.54	<0.40	< 2.1	4
109	10.8	5.23	5.0	20	4.9	0.93	< 1.4	8
110	5.0	2.14	86	14	4.4	1.4	< 1.4	2
111	11.6	5.69	3.3	3.2	0.94	<0.40	< 6.2	4
112	9.9	5.28	4.8	0.77	<0.36	<0.40	<15	5
113	10.9	6.67	1.3	.....	.....	.....	.....	701
114	8.9	4.19	13	2.0	0.57	<0.40	< 1.7	4
115	10.3	7.57	0.58	.....	.....	.....	.....	1337
116	10.2	3.79	19	4.7	1.4	<0.40	< 2.3	7
117	9.4	4.80	7.5	1.8	0.53	<0.40	<14	1
118	9.8	4.83	7.3	1.6	0.51	<0.40	< 1.9	4
119	10.9	7.00	0.98	.....	.....	.....	.....	577
120	11.4	6.51	1.5	0.55	<0.30	<0.40	<17	10
121	11.2	....	....	1.1	<0.30	<0.40	< 1.6	85
122	9.4	4.56	9.3	2.6	0.82	<0.40	< 1.7	12
123	7.3	3.47	25	3.7	1.3	0.65	< 2.1	2
124	10.1	4.91	6.7	1.1	0.42	<0.40	< 2.2	5
125	12.8	5.94	2.6	14	6.2	1.4	<11	2
126	9.5	4.29	12	2.6	0.77	<0.40	< 1.5	2
127	11.6	6.36	1.8	0.41	<0.26	<0.40	< 2.0	6
128	11.8	6.16	2.1	.....	.....	.....	.....	344
129	10.8	5.65	3.4	0.74	<0.34	<0.40	< 2.6	12
130	9.4	5.33	4.6	0.57	<0.26	<0.40	< 2.4	3
131	12.2	6.94	1.0	.....	.....	.....	.....	367
132	10.7	5.69	3.3	0.82	<0.41	<0.40	< 1.8	12
133	9.9	5.85	2.8	0.45	<0.32	<0.40	< 1.5	6
134	9.1	3.75	20	5.0	1.5	0.53	< 1.7	1
135	9.6	5.31	4.7	0.61	<0.30	<0.40	< 2.2	11
136	9.0	4.33	11	1.7	0.58	<0.40	< 7.0	13
137	11.6	5.95	2.6	0.66	<0.50	<0.40	< 2.4	2
138	10.8	5.95	2.6	0.50	<0.33	<0.40	< 2.1	16
139	11.5:	5.57	3.7	1.1	<0.34	<0.40	< 1.8	5
140	9.4	5.01	6.1	1.3	<0.45	<0.40	< 1.5	2
141	8.7	4.75	7.8	1.3	<0.60	<0.40	< 2.8	1
142	12.6	6.35	1.8	0.43	<0.39	<0.40	4.6	43
143	10.7	5.00	6.2	1.5	0.59	<0.40	< 2.5	3
144	7.5	3.10	36	8.7	2.6	0.75	< 1.8	6
145	10.8	6.00	2.5	2.4	0.99	<0.40	< 1.3	6
146	12.2	8.28	0.30	....	.....	.....	....	536
147	11.9	6.12	2.2	1.4	0.62	<0.40	< 8.3	3
148	12.4	7.50	0.62	....	.....	.....	....	722
149	11.6	5.58	3.6	9.8	2.5	0.71	3.2	63
150	9.5	5.20	5.2	3.1	0.8	<0.40	< 2.3	1
151	10.3	5.10	5.7	1.2	0.45	<0.40	<13	2
152	12.8	6.61	1.4	....	.....	.....	....	562
153	9.0	4.47	10	1.8	0.71	<0.40	<13	6
154	11.9	6.90	1.1	0.48	<0.43	<0.40	< 2.1	4
155	12.2	6.05	2.4	0.63	<0.38	<0.40	<14	4
156	7.5	3.56	23	6.5	2.2	2.0	2.0	2
157	12.2	6.32	1.8	....	.....	.....	....	589
158	9.7	4.68	8.3	1.7	0.54	<0.40	<12	4
159	7.9	3.66	21	4.1	1.2	0.46	< 1.5	6
160	9.8	4.86	7.1	1.4	0.48	<0.40	< 1.4	14

TABLE 1—*Continued*

Star No.	m_I	m_K	F_ν 2 μm	F_ν 12 μm	F_ν 25 μm	F_ν 60 μm	F_ν 100 μm	Δφ ″
161	11.7	5.43	4.2	0.80	0.47	<0.70	< 6.7	13
162	8.8	4.48	10	2.5	0.81	<0.48	< 5.9	4
163	11.5	5.58	3.6	0.55	<0.33	<0.40	< 3.7	19
164	9.6	5.08	5.8	2.2	0.60	<0.43	<12	2
165	10.7	5.24	5.0	0.87	<0.39	<0.40	< 2.5	5
166	10.3	6.65	1.4	....	.....	.....	....	898
167	8.8	4.40	11	1.9	0.56	<0.40	< 2.4	18
168	11.9	6.96	1.0	....	.....	.....	....	610
169	12.8	7.38	0.69	....	.....	.....	....	373
170	9.0	4.51	9.7	2.2	0.71	<0.40	< 2.0	1
171	10.8	5.27	4.8	1.5	<0.57	<0.41	<15	16
172	11.7	5.33	4.6	1.3	0.47	<0.51	< 4.1	18
173	9.8	5.18	5.3	0.88	<0.47	<0.46	<10	5
174	9.8	5.63	3.5	0.75	<0.33	<0.40	< 2.1	10
175	12.2	5.08	5.8	1.7	0.57	<0.47	<17	9
176	12.1	5.77	3.1	0.39	<0.49	<0.49	<27	7
177	9.3	4.69	8.2	1.5	0.51	<0.40	<12	6
178	11.9	7.65	0.54	.....	.....	.....	.....	446
179	5.0	1.03	240	70	21	5.3	3.3	4
180	12.5	6.68	1.3	.....	.....	.....	.....	485
181	12.8	5.64	3.4	0.87	<0.32	<0.44	<26	9
182	12.6	6.02	2.4	0.73	<0.35	<1.6	<20	11
183	10.4	4.39	11	2.6	0.80	<0.48	< 2.5	3
184	12.2	6.55	1.5	.....	.....	.....	.....	593
185	11.9	9.11	0.14	.....	.....	.....	.....	96
186	10.1	5.63	3.5	1.1	0.60	<0.40	< 1.8	14
187	10.8	5.64	3.4	0.84	<0.36	<0.45	< 3.9	10
188	10.2	5.46	4.1	1.4	0.70	<1.5	<12	2
189	10.2	5.54	3.8	0.93	<0.38	<0.44	< 2.5	19
190	9.2	4.76	7.7	1.8	0.66	<0.42	< 2.9	3
191[1]	8.9	4.69	8.2	3.0	0.95	<0.40	< 2.9	76
192[1]	11.5	4.77	7.7	3.0	0.95	<0.40	< 2.9	12
193	8.6	4.29	12	2.9	0.95	1.2	<15	20
194	10.3	6.28	1.9	.....	.....	.....	.....	477
195	11.5	4.88	6.9	3.1	0.91	<1.1	< 8.2	96
196	10.0	5.36	4.5	0.78	<0.37	<0.40	<15	12
197	9.3	5.48	4.0	0.65	<0.29	<1.8	<13	71
198	12.3	6.33	1.8	1.2	<0.27	<0.40	< 2.5	20
199	7.6	3.85	18	3.3	1.1	<0.40	<13	3
200	10.8	6.23	2.0	0.39	<0.27	<0.40	<11	3
201	8.4	4.32	12	2.1	0.66	<0.44	<11	8
202	8.8	4.83	7.3	1.2	<0.51	<0.44	< 2.4	9
203	9.5	4.91	6.7	2.8	0.79	<0.40	< 6.9	3
204	10.3	6.37	1.8	0.45	<0.29	<0.40	< 2.2	13
205	9.5	5.72	3.2	0.78	<0.27	<0.40	< 2.0	5
206	9.8	5.50	3.9	0.84	<0.31	<0.40	< 7.9	4
207	12.2	10.56	0.037	.....	.....	.....	.....	209
208	10.0	5.72	3.2	8.9	3.1	0.55	< 1.4	2
209	5.0	0.79	300	45	14	3.9	2.8	20
210	11.4	5.85	2.8	2.2	0.69	<0.40	< 1.6	7
211	12.2	7.61	0.56	.....	.....	.....	.....	893
212	10.8	6.34	1.8	0.42	<0.29	<0.40	< 1.9	17
213	10.9	6.27	1.9	.....	.....	.....	.....	355
214	8.5	4.39	11	1.9	0.59	<0.40	< 1.0	5
215	8.0:	3.88	17	3.4	1.3	<0.45	< 8.1	3
216	11.5	....	.....	.....	.....	.....	.....	515

NOTE.—We give Fuenmayor's star number in col. (1) and *I*-magnitude in col. (2). We give our measured *K*-magnitude in col. (3), and the conversion to Jy in col. (4). In cols. (5)–(8) we give the non–color-corrected fluxes measured at 12, 25, 60, and 100 μm by *IRAS* of the nearest source in the *Point Source Catalog* (for separations less than 90″). In col. (9) we report the angular separation between the position given by Fuenmayor and the position of the nearest source in the *IRAS Point Source Catalog*.

[1] These two positions locate the same *IRAS* source; they may be confused.

TABLE 2

COMPARISON BETWEEN K-BAND MAGNITUDES

STAR[a]	m_K This Paper	m_K TMSS
+40115(7)	2.31	2.29
+40120(25)	2.63	2.70
+30110(29)[b]	1.87	2.13
+30114(49)[b]	1.55	1.97
+20115(84)	2.92	2.95
+20120(100)	1.66	1.76
+30127(110)	2.14	2.14
+30143(179)	1.03	1.00
+10121(209)	0.79	0.75

[a] We list Fuenmayor's star number in parentheses after the IRC name. We measured $m_K = 2.20$ mag for Fuenmayor's star 44, yet this object is not found in the TMSS, which was complete to $m_K = 3.0$ mag. It is probably a star that has brightened.

[b] Found to be variable from its χ^2 excess in the TMSS.

envelope emission is important for many of the stars in Fuenmayor's list. For most of Fuenmayor's stars, an *IRAS* source lies within 30″ of the position given by Fuenmayor and has the infrared spectral energy distribution expected of a star (that is, flux density decreasing with wavelength). Three stars, Nos. 85, 101, and 193 exhibit an increase in the flux density at 60 μm, and they may be confused with other Galactic plane sources. We have found three errors in the *IRAS Point Source Catalog* magnitudes reported by Claussen *et al.* (1987). IRC+60113, IRC +71077, and IRC +30219 have 12 μm magnitudes of 0.10, −1.41, and −4.93, respectively.

III. ANALYSIS

a) Completeness

Because we are interested in using star counts to determine the spatial distribution of the carbon stars, it is essential that we assess the completeness of Fuenmayor's (1981) survey. Although he reports that the survey is complete to $I = 11$ mag, it does not include at least one carbon star, IRC +40120 (Claussen *et al.* 1987), which lies in the region he surveyed and has $I = 6.8$ mag. Nevertheless, Fuenmayor's survey is probably almost complete because a subsequent objective-prism survey for carbon stars in the anticenter region by Maehara and Soyano (1987) found only 21 additional carbon stars, some of which were outside the zone surveyed by Fuenmayor. Another class of carbon star not found by Fuenmayor is objects with very large amounts of circumstellar extinction. The mass-losing carbon star GL 809 is a bright 10 μm source and CO radio emitter (Zuckerman and Dyck 1986) and was not identified by Fuenmayor, presumably because it is very faint at I. In any case, since the typical $(I-K)$ color of the stars with apparent $K > 5.0$ mag is almost 6 mag, Fuenmayor's sample probably becomes incomplete for $K > 5.0$ mag.

b) Extinction

The stars in this sample are sufficiently far away and sufficiently close to the Galactic plane that extinction by dust can be appreciable even at 2 μm. The effects of reddening are displayed in Figure 1, where we compare the $(I-K)$ colors with the K-magnitudes of the observed stars. For the brightest stars, those with $K < 3$ mag, we find that $(I-K)$ is typically near 3 mag, in agreement with the average value of 2.71 found by Claussen *et al.* (1987). In the Magellanic Clouds, where the metallicity is appreciably lower than in the solar neighborhood, the I-band photometry of Richer (1981) and the K-band photometry of Cohen *et al.* (1981) show that carbon stars have nearly the same intrinsic color, $(I-K) = 2.8$ mag, as in the solar neighborhood.

The stars that are fainter than $K = 3$ mag in the anticenter direction have $(I-K)$ colors that are generally redder than 3 mag. We interpret this result to mean that interstellar reddening is significant. For stars as faint as $K = 5$ mag, $(I-K)$ colors as red as 5 and 6 mag are common in Figure 1.

Circumstellar reddening is not normally important because, as can be seen in Table 1, in almost all cases, $F_\nu(12\ \mu\text{m}) < F_\nu(2\ \mu\text{m})$ which implies that the amount of circumstellar dust is not very large (Jura 1986*b*).

Classical optical surveys of the amount of dust do not penetrate to the distances at which the bulk of the carbon stars in this survey are located (FitzGerald 1968). Thus, to infer the amount of interstellar obscuration, we model the interstellar medium as a uniform slab with half-thickness vertical to the Galactic plane of $d_{1/2}$. The extinction gradient in this slab can be estimated from measurements of the gas content. According to Scoville and Sanders (1987), most of the gas in the anticenter direction is atomic rather than molecular. Also, the column density of hydrogen gas perpendicular to the plane in the anticenter direction out to 6.5 kpc beyond the Sun is approximately constant at 5.5 $M_\odot$ pc^{-2}, which gives a column density of hydrogen atoms, N_H, of 6.9×10^{20} H atoms cm^{-2}. If we assume a uniform layer of gas with a half-thickness, $d_{1/2}$, of 100 pc, then the average density of gas atoms is 1.1 cm^{-3}, similar to the value in the solar neighborhood (see Spitzer 1978). With $A_K/E(B-V) = 0.38$ and $N_\text{H}/E(B-V) = 5.8 \times 10^{21}$ atoms cm^{-2} mag^{-1} (Savage and Mathis 1979), then we find that

$$A_K/N_\text{H} = 6.6 \times 10^{-23} . \tag{1}$$

with $n(\text{H}) = 1.1$ cm^{-3} in the plane, this corresponds to a K extinction of 0.2 mag kpc^{-1}. If a star is at Galactic latitude b, and at distance d (kpc), we assume that the extinction to the star, A_K, is given by

$$A_K = [\Delta(A_K)_0/\Delta d]d \qquad \text{if } d \sin b < d_{1/2} , \tag{2a}$$

$$A_K = [\Delta(A_K)_0/\Delta d]d_{1/2}/\sin b \quad \text{if } d \sin b > d_{1/2} , \tag{2b}$$

where $\Delta(A_K)_0/\Delta d$ is a constant. For a conservative low estimate to the average amount of reddening, we adopt $\Delta(A_K)_0/\Delta d = 0.15$ mag kpc^{-1}.

We now proceed on the basis that we have a better understanding of the absolute K-magnitude and intrinsic $(I-K)$ color of carbon stars than we do of the amount of reddening in the anticenter direction. We assume that all carbon stars have $M_K = -8.1$ mag and intrinsic $(I-K)$ color of 2.8 mag. We can then calculate the colors of the stars as a function of apparent K-magnitude if we know the reddening law (A_I/A_K) and the extinction gradient. The results for this calculation are shown in Figure 1 for three estimates of these parameters.

Our simple model predicts a linear relationship between $(I-K)$ color and m_K. In fact, there is a substantial variation in the intrinsic $(I-K)$ colors of carbon stars of 1.29 mag (Claussen *et al.* 1987). Fuenmayor's (1981) photographic photometry is not highly precise, and the interstellar medium is

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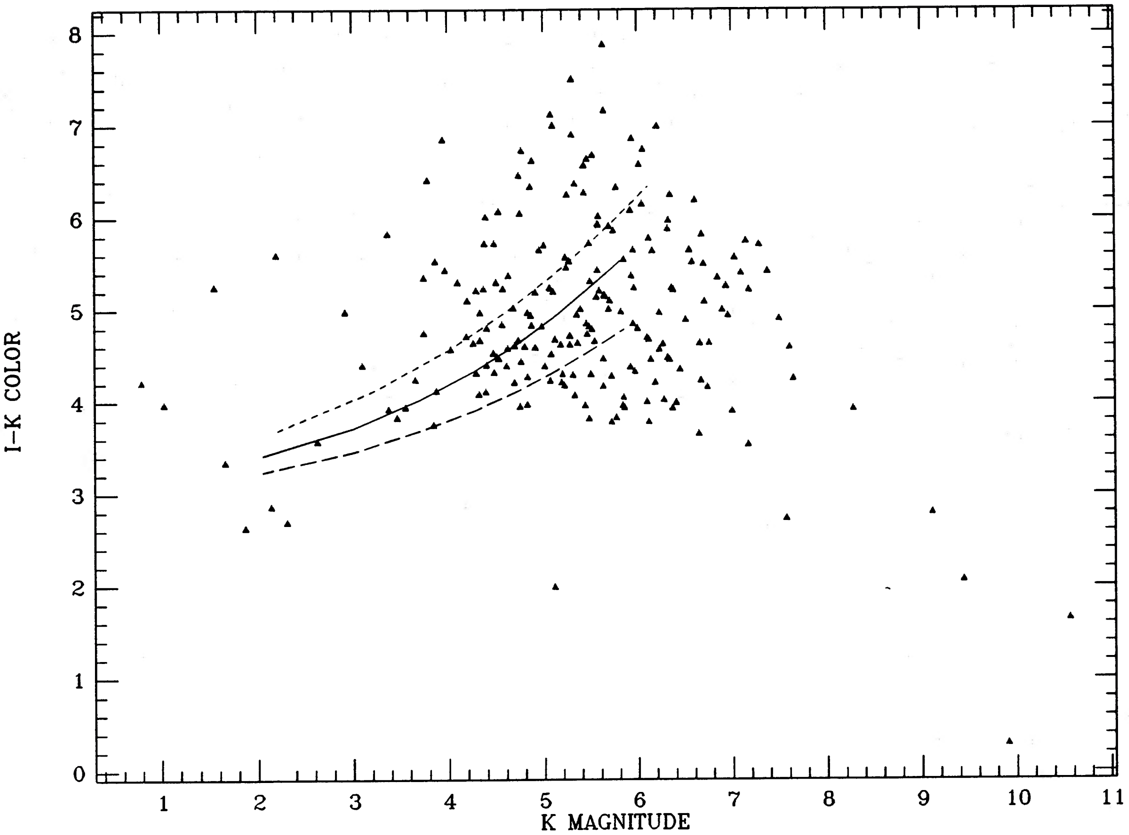

FIG. 1.—Plot of the $(I-K)$ color vs. K-magnitude of the 212 stars in our sample. Because the survey was conducted to be complete to $I = 11$ mag, stars that are faint at K ($K > 6$ mag) cannot have been detected unless their $(I-K)$ color was relatively blue, even though 30% of Fuenmayor's stars are fainter than his completeness limit of $I = 11.0$ mag. The solid line represents the prediction for a model where all the stars have $M_K = -8.1$ mag, $(I-K) = 2.8$ mag, and there is 0.15 K mag kpc^{-1} of extinction and $A_I = 5.11 A_K$. The short-dashed and long-dashed curves represent models with 0.30 K mag kpc^{-1} and 0.15 K mag kpc^{-1} of extinction, respectively, for $A_I = 3.95 A_K$.

quite patchy. Thus, the wide dispersion in $(I-K)$ color as a function of m_K displayed in Figure 1 is not surprising.

We find that the average colors of faint carbon stars in our sample are redder than indicated by the expected extinction gradient (0.15 mag kpc^{-1}) and the reddening law given by Cohen *et al.* (1981), which predicts $A_I/A_K = 5.11$. If we adopt the flatter extinction curve given by Savage and Mathis (1979), where $A_I/A_K = 3.95$, then the discrepancy is even worse unless we adopt a much higher extinction gradient, 0.3 mag kpc^{-1}.

With 0.3 K mag kpc^{-1} of extinction, in order not to exceed the column density of interstellar gas vertical to the Galactic plane inferred by Scoville and Sanders (1987), we require that $d_{1/2} < 75$ pc. However, the half-thickness of the interstellar matter is not well determined by our analysis.

Fich and Blitz (1984) propose that in the outer Galaxy, the extinction is about 3 mag at V for distances about 3 kpc from the Sun. This corresponds to about 0.11 mag kpc^{-1} of extinction at K (Rieke and Lebofsky 1985). This value of the K extinction gradient is smaller than we find, but the optical data may preferentially select lines of sight with less extinction and many not imply any major disagreement between these two estimates for the amount of extinction.

c) Luminosities

We assume that the average absolute magnitude for carbon stars is $M_K = -8.1$ (Claussen *et al.* 1987). To include the Malmquist bias in using star counts to determine the structure of the Galaxy (see Mihalas and Binney 1981), we assume a Gaussian distribution of the absolute K-magnitudes of the carbon stars such that

$$n(M_K) = (\pi\sigma_{M_0}^2)^{-1/2} \exp\left[-(M_K + 8.1)^2/\sigma_{M_0}^2\right] . \tag{3}$$

From the data in Cohen *et al.* (1981), we adopt $\sigma_{M_0} = 0.65$ mag.

d) Spatial Distribution of Carbon Stars

In order to interpret the counts of carbon stars seen in Fuenmayor's survey, we adopt a simple model invoking an exponential dependence of source density on galactocentric radius (r) and height above the Galactic plane (z):

$$n = n_0 \exp(-r/r_{\rm disk}) \exp(-|z|/z_0) . \tag{4}$$

Here r is the galactocentric radius measured outward from the Sun (where $r = 0$) and $r_{\rm disk}$ is a parameter to measure the scale length of carbon stars in the plane of the Milky Way; z_0 is the scale height above the Galactic plane. Because z_0 is determined by the amount of matter in the disk, it can be a function of distance from the center of the Galaxy, but we assume that z_0 is constant and independent of galactocentric distance. Numerical results not shown here indicate that the observed counts are more sensitive to $r_{\rm disk}$ than z_0 as a function of r. Also, numerical results show our conclusions are not very sensitive

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to the possible range of z_0 given by Claussen *et al.* (1987). At the Galactic longitudes of interest here, we do not anticipate any significant warping of the Galactic plane (Henderson, Jackson, and Kerr 1982). For the total density of stars in the Milky Way, a typical spiral galaxy, we expect that $r_{\rm disk} = 4$ kpc (Mihalas and Binney 1981).

In order to compare the star counts with the models, we divide the irregular zone surveyed by Fuenmayor into strips parallel to the Galactic plane. Each strip is 1° in latitude, while the length in longitude depends upon the height above the Galactic plane, which we take from Fuenmayor's Figure 2. For example, for the zone $0° < b < 1°$ the longitude strip is 36°, while for the zone $4° < b < 5°$ the longitude strip is 9°. There are notable differences in the longitude coverage north and south of the Galactic plane.

We further subdivide the sample into stars of different apparent magnitudes as a function of latitude within the different longitude strips, displaying the results for the K-magnitude ranges 3–4, 4–5, and 5–6. As discussed above, the sample becomes seriously incomplete for $K > 6$ mag, and we do not consider the data to be useful for fainter objects. We consider models with both 0.15 K mag kpc^{-1} and 0.30 K mag kpc^{-1} of extinction. In Figures 2*a*–2*e* we display the results of our calculations for the numbers of stars in the different lattitude bins versus the observed numbers of stars.

Figure 2*a* shows the results for the expected star counts versus latitude for stars in the range $3 < m_K < 4$ with 0.3 K mag kpc^{-1} of extinction. Because these stars are relatively nearby (<2 kpc), there is not much difference between the models with 0.15 K mag kpc^{-1} of extinction and those with 0.30 K mag kpc^{-1} of extinction, independent of A_I/A_K. The three displayed models have $r_{\rm disk} = 4000$ pc, ∞, and −4000 pc, respectively. (A negative value of $r_{\rm disk}$ corresponds to a case where the number density of carbon stars increases in the anticenter direction as proposed by Fuenmayor 1981.) The good agreement between the observations and the models indicates that the local density and scale height for the carbon stars inferred by Claussen *et al.* (1987) are reasonably accurate. Because Fuenmayor sampled only a very limited volume of the local Milky Way, there are not many stars in this region, and

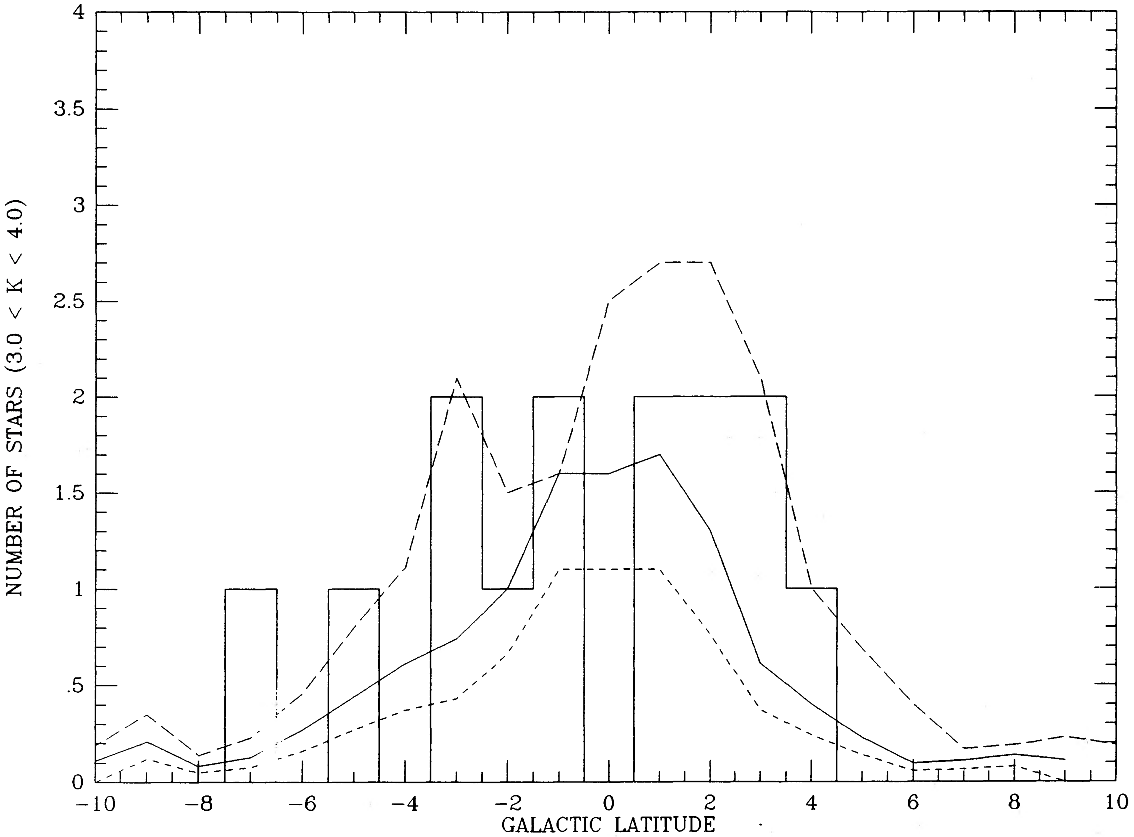

FIG. 2*a*

FIG. 2.—(*a*) Plot comparing the observed numbers of stars at different latitude bins (the histogram) with models. The solid curve refers to a model with constant density throughout the disk ($r_{\rm disk} = \infty$) and a scale height everywhere of 200 pc. Note that this curve displays wiggles at high latitudes because, in the irregular area surveyed by Fuenmayor, some of the longitude strips are longer than others. The short-dashed curve represents a model where the density falls in the anticenter region with a scale length $r_{\rm disk} = 4000$ pc. The long-dashed curve represents a model with $r_{\rm disk} = -4000$ pc. We assume 0.30 K mag kpc^{-1} of extinction. (*b*) Plot of number count compared with models for stars in the magnitude range $4.0 < m_K < 5.0$. We assume 0.30 K mag kpc^{-1} of extinction. The solid curve refers to a model of constant n_0 in the plane, while the short-dashed curve refers to a model where the density falls with $r_{\rm disk} = 4000$ pc. The long-dashed curve refers to a model where the density increases outward in the sense that $r_{\rm disk} = -4000$ pc. (*c*) Similar to (*b*), except that we consider models with 0.15 *K* mag kpc^{-1} of extinction. The solid curve refers to a model with a constant density of carbon stars, while the dashed curve refers to a model where $r_{\rm disk} = 4000$ pc. (*d*) Same as (*b*), but for stars in the magnitude range $5.0 < m_K < 6.0$. (*e*) Same as (*c*), but for stars in the magnitude range$5.0 < m_K < 6.0$.

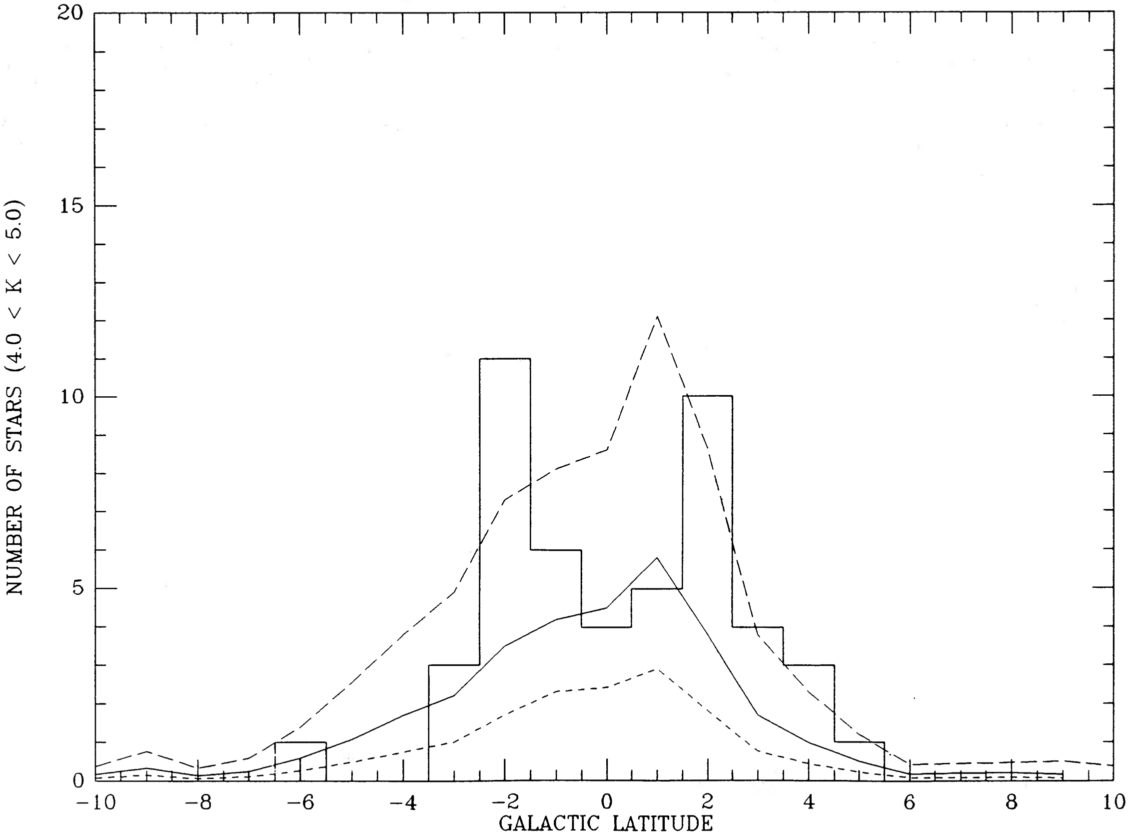
20
15
10
5
0
NUMBER OF STARS (4.0 < K < 5.0)
−10
−8
−6
−4
−2
0
2
4
6
8
10
GALACTIC LATITUDE

FIG. 2b

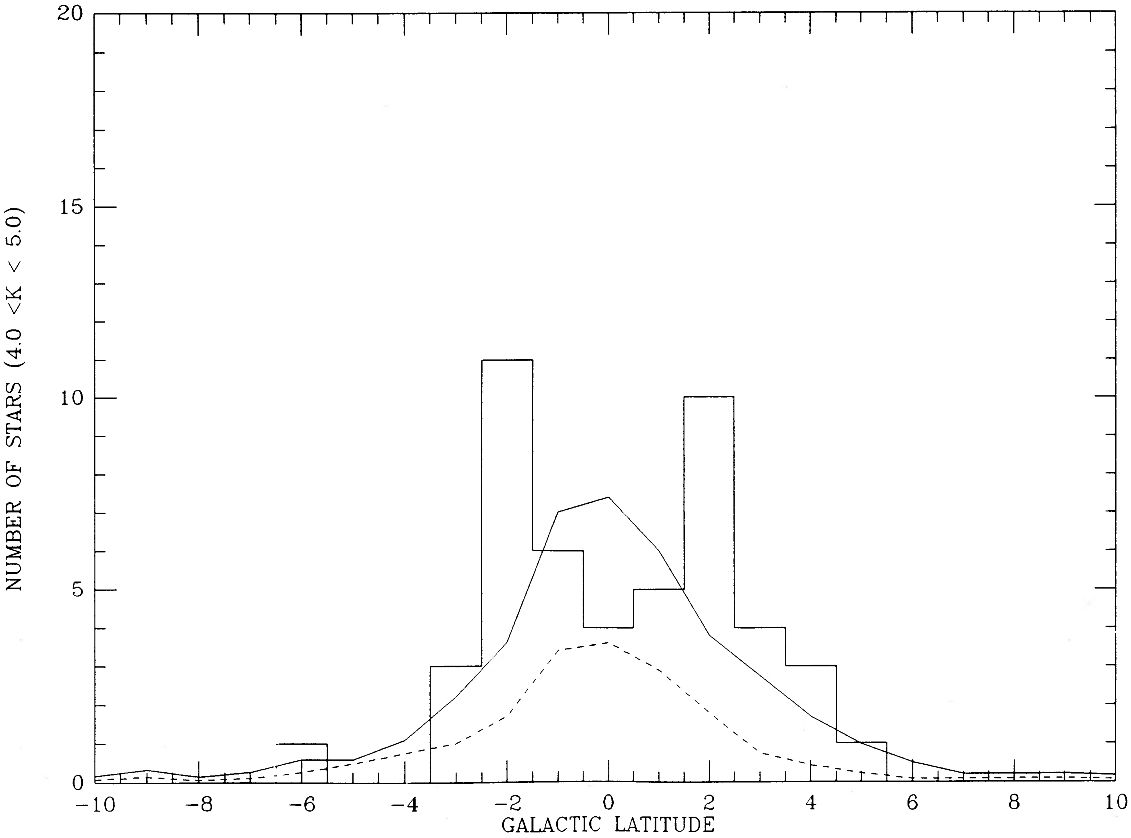
20
15
10
5
0
NUMBER OF STARS (4.0 <K < 5.0)
−10
−8
−6
−4
−2
0
2
4
6
8
10
GALACTIC LATITUDE

FIG. 2c

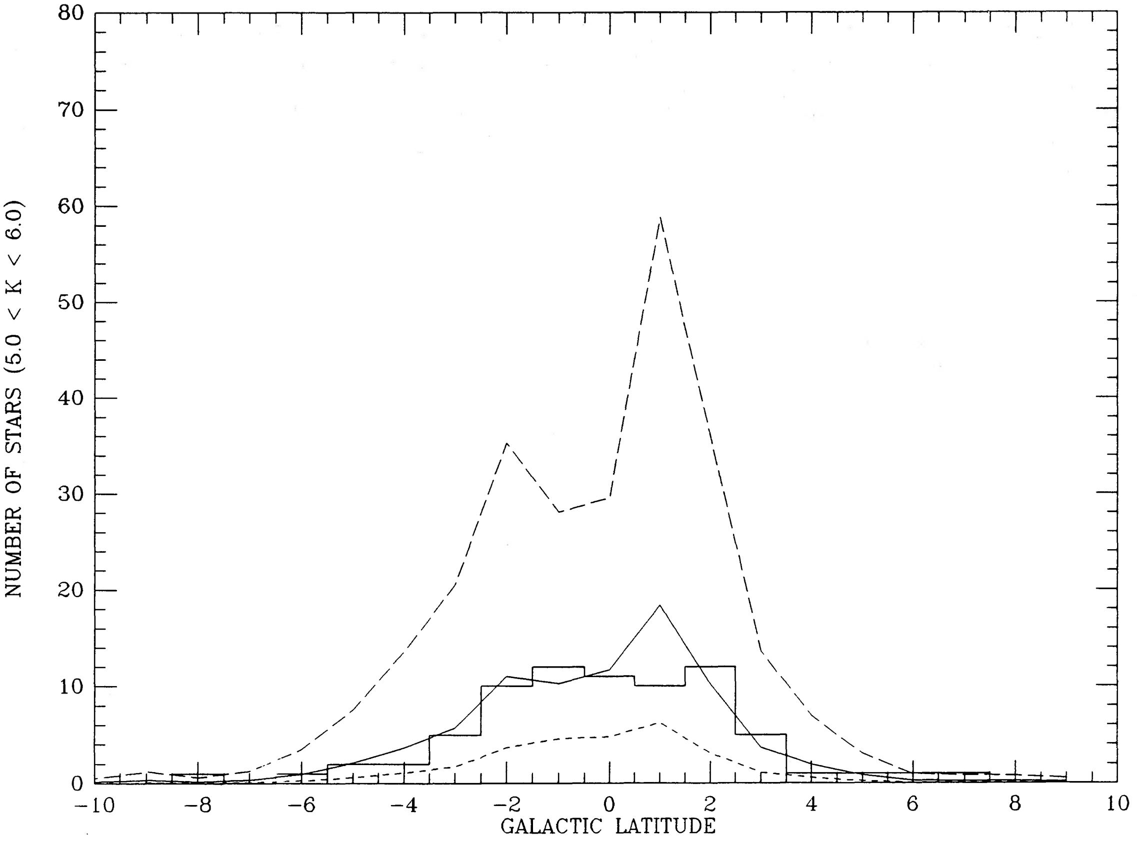
NUMBER OF STARS (5.0 < K < 6.0)
0
10
20
30
40
50
60
70
80
−10
−8
−6
−4
−2
0
2
4
6
8
10
GALACTIC LATITUDE

FIG. 2*d*

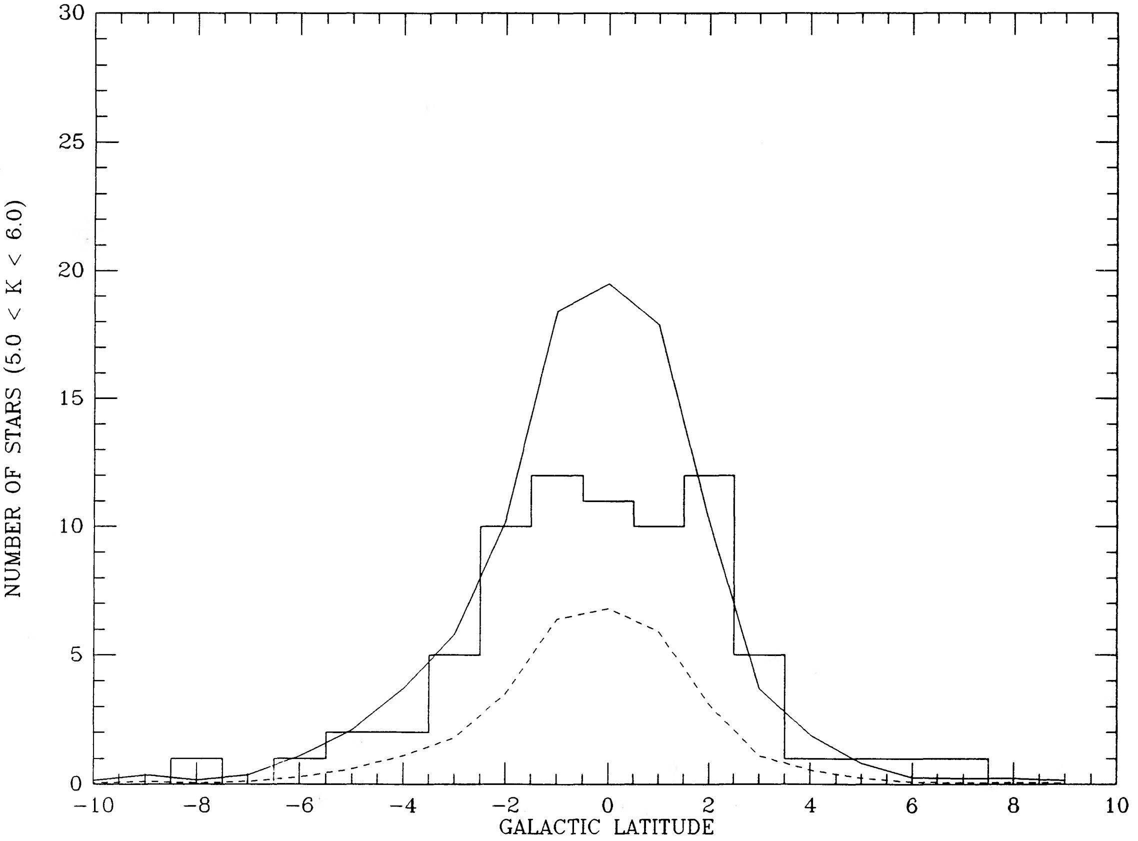
NUMBER OF STARS (5.0 < K < 6.0)
0
5
10
15
20
25
30
−10
−8
−6
−4
−2
0
2
4
6
8
10
GALACTIC LATITUDE

FIG. 2*e*

his inferred density of 20 kpc^{-3} has much less statistical weight than does the value of the density inferred by Claussen *et al.* (1987).

The results shown in Figures 2*b* and 2*c* are for stars with $4.0 < m_K < 5.0$ mag and indicate a substantial difference between the model with no gradient in the number density of stars and the models with gradients in the number density of stars. The model with no density gradient is clearly more consistent with the data than the model with a decreasing number of carbon stars in the outer Galaxy. Our value for the density of 100 kpc^{-3} is in reasonable agreement with the value of 50 kpc^{-3} given by Fuenmayor for stars at ∼4 kpc from the Sun in the anticenter direction.

Figures 2*d* and 2*e* display the models versus observations for stars with $5 < K < 6$ mag corresponding to $3.3 < r(\text{kpc}) < 4.7$ for $\Delta(A_K)_0/\Delta d = 0.15$ mag kpc^{-1}. In this magnitude range, the star counts are probably incomplete. These figures are consistent with the hypothesis that the model that best represents the real Galaxy is the one with no gradient in the space density of carbon stars. This result is in marked contrast to the galactocentric density dependence of all stars, which falls with a scale length of 4 kpc.

IV. MASS-LOSS RATES

The present sample can be used to determine whether there is any systematic difference in the mass-loss rates between the stars of solar metallicity in the neighborhood of the Sun and those of lower metallicity in the anticenter region.

Claussen *et al.* (1987) have estimated an average mass-loss rate for carbon stars in the solar neighborhood of 2×10^{-7} $M_\odot$ yr^{-1}. Here we use the same formalism to estimate the dust-loss rate of Fuenmayor's stars from their infrared emission, which we presume to result from circumstellar dust. By assuming a dust-to-gas ratio, it is then possible to derive a total gas-loss rate.

From Jura (1986*b*), we write

$$dM/dt = 1.7 \times 10^{-7} F_\nu(60\ \mu\text{m}) r_{\text{kpc}}^2 L_4^{-1/2} \lambda_{10}^{1/2} v_{15}\ , \qquad (5)$$

where dM/dt is expressed in units of $M_\odot$ yr^{-1}. Also, r_{kpc} is the distance to the star in kiloparsecs, L_4 is the luminosity of the star in units of 10^4 $L_\odot$, λ_{10} is the average wavelength of the light emergent from the star and circumstellar shell together in units of 10 μm, v_{15} is the outflow speed of the circumstellar material in units of 15 km s^{-1}, and $F_\nu(60\ \mu\text{m})$ is the flux measured at the Earth from the circumstellar shell in janskys. Most of the stars that we observed in the anticenter region in the K-magnitude region of interest were detected at 25 μm but not at 60 μm. Therefore, we scale the above equation to use the 25 μm flux to estimate the mass-loss rate. In a circumstellar envelope around carbon stars we expect that F_ν varies approximately as $\nu^{1.5}$ (Jura 1986*b*), in agreement with the observed colors of carbon stars (Claussen *et al.* 1987). We rewrite equation (5) to give

$$dM/dt = 4.6 \times 10^{-8} F_\nu(25\ \mu\text{m}) r_{\text{kpc}}^2 L_4^{-1/2} \lambda_{10}^{1/2} v_{15}\ . \qquad (6)$$

We derive the distances to the stars from the assumption that $M_K = -8.1$ mag and that there is an extinction gradient of 0.15 K mag kpc^{-1}. Given the known colors of carbon stars, if $M_K = -8.1$ mag, this generally implies that $L_4 = 1$ to within a factor of 1.2 (see Claussen *et al.* 1987), and we therefore adopt $L_4 = 1$. Similarly, nearly all the stars we consider have $F_\nu(12\ \mu\text{m}) < F_\nu(2\ \mu\text{m})$, so, as with the carbon stars in the solar neighborhood, we adopt $\lambda_{10} = 0.22$. As did Claussen *et al.* (1987), we assume that $v_{15} = 1$.

The outflow velocities from the carbon stars in the anticenter direction have not been measured, and this may overestimate the outflow rate. As discussed in Jura (1986*a*), radiation pressure on dust may control the outflow velocities in mass-losing stars so that stars of lower metallicities may, on the average, have lower outflow velocities. If χ is the metallicity, in the simplest model, we expect that v varies as $\chi^{1/2}$. However, the constants of proportionality in equations (5) and (6) also depend upon the dust-to-gas ratio, which, in the simplest models, is inversely proportional to the metallicity. Therefore, on the average, because the outflow velocities may be lower but the gas-to-dust ratio may be higher, equations (5) and (6) may underestimate the mass-loss rates from mass-losing carbon stars by a factor of $\chi^{1/2}$.

We wish to consider a sample of stars that is far enough from the Sun that the metallicity is significantly lower than in the solar neighborhood, but sufficiently near that the sample is reasonably complete. Thus, we consider all the stars in the magnitude range $4.0 < K < 5.0$ mag, corresponding to $2.3 < r(\text{kpc}) < 3.3$ for $M_K = -8.1$ mag and a K-band extinction gradient of 0.15 mag kpc^{-1}. These stars may have an average metallicity about a factor of 0.7 of that in the solar neighborhood (see below).

In Table 3 we list the 50 stars in our sample with $4.0 < K < 5.0$, their inferred distance, the measured flux at 25 μm, and their inferred mass-loss rate. The average mass-loss rate for the stars in Table 3 is 1.2×10^{-7} $M_\odot$ yr^{-1}, a factor of 1.7 less than the average value of 2.0×10^{-7} $M_\odot$ yr^{-1} for the stars in the solar neighborhood given by Claussen *et al.* (1987). Such a difference can be understood if radiation pressure on grains plays a key role in driving the mass loss from carbon stars (see Jura 1986*a*).

As discussed above, our determination of the mass-loss rate probably scales as the metallicity to the one-half power. Because these stars have an average metallicity of ∼0.7 of the Sun's value, the difference in the inferred average mass-loss rates between the two sets of carbon stars is probably not strongly affected by our assumption that the dust-to-gas ratio is the same for all carbon stars, independent of their metallicity.

In Figure 3 we display a histogram of the $K - [12\ \mu\text{m}]$ colors of the stars in Fuenmayor's survey for which we have measured $4.0 < m_K < 5.0$ mag and for which there are measured fluxes in the *IRAS Point Source Catalog*. For the stars in the anticenter direction, we find K_0, the apparent K-magnitude the stars would have in the absence of extinction under the assumption that they are subject to 0.15 K mag kpc^{-1} of extinction. We also find $m(12)$, the color-corrected flux at 12 μm in magnitudes where 0 mag corresponds to 28.3 Jy (see Hacking *et al.* 1985). Note that the color-correction procedure essentially increases the magnitude at 12 μm by an additive constant of 0.25 mag. The average $[K_0 - m(12)]$ color of the stars in the anticenter region in the K-magnitude range $4.0 < K < 5.0$ is 1.09 mag. In contrast, the average for the same quantity for the carbon stars in the solar neighborhood is 1.84 mag (Claussen *et al.* 1987). Had we assumed a larger extinction gradient, this discrepancy would have been even greater.

Another difference between the two samples is that fewer stars in the anticenter region display are variables. For the local stars, about 20% have a probability >50% of being variable in the *IRAS Point Source Catalog*. In the anticenter sample of stars with $4.0 < m_K < 5.0$ mag, only 2 out of 50 (4%)

TABLE 3

MASS-LOSS RATES FOR STARS WITH $4.0 < K < 5.0$

Star	D (kpc)	$F_\nu(25\ \mu m)$ (Jy)	dM/dt ($10^{-7}\ M_\odot\ yr^{-1}$)
1	3.0	<0.48	<0.93
4	2.6	0.87	1.3
10	2.3	0.73	0.83
11	2.6	0.98	1.4
21	2.5	1.0	1.3
27	3.2	0.35	0.77
28	2.9	1.0	1.8
37	3.0	2.4	4.7
38	2.8	0.53	0.90
63	3.1	0.66	1.4
64	2.7	0.90	1.4
65	3.2	0.37	0.82
67	3.0	0.59	1.1
71	2.9	0.49	0.89
79	2.6	0.82	1.2
80	3.1	0.86	1.8
85	2.7	0.78	1.2
86	2.6	0.96	1.4
90	2.8	0.52	0.88
94	2.8	0.65	1.1
95	3.3	0.51	1.2
101	2.4	1.2	1.5
102	2.9	0.64	1.2
103	2.3	0.97	1.1
108	3.2	0.54	1.2
114	2.4	0.57	0.71
117	3.1	0.53	1.1
118	3.1	0.51	1.1
122	2.8	0.82	1.4
124	3.2	0.42	0.93
126	2.5	0.77	1.0
136	2.6	0.58	0.85
141	3.0	<0.60	<1.2
153	2.7	0.71	1.1
158	2.9	0.54	0.98
160	3.1	0.48	1.0
162	2.7	0.81	1.3
167	2.6	0.56	0.82
170	2.7	0.71	1.1
177	3.0	0.51	0.99
183	2.6	0.80	1.2
190	3.0	0.66	1.3
191	3.0	0.95[a]	1.8
192	3.0	0.95[a]	1.8
193	2.5	0.95	1.3
195	3.2	0.91	2.0
201	2.6	0.66	0.96
202	3.1	<0.51	<1.1
203	3.2	0.79	1.7
214	2.6	0.59	0.86

[a] Possibly confused.

of the stars have a probability >50% of being variable; these two are 191 and 192, which may appear variable because they are confused. As shown by Jura (1986*b*) and Claussen *et al.* (1987), there is a strong correlation between infrared variability and a high mass-loss rate. Also, even though more than 80% of the stars in Fuenmayor's anticenter sample with $4.0 < m_K < 5.0$ mag have been identified for some time in Stephenson's (1973) catalog of carbon stars, only two, Fuenmayor stars 28 and 201, which are EF Aur and GL Ori, respectively, are identified as optical variables in the *General Catalog of Variable Stars* (Kholopov *et al.* 1985).

In contrast to the [2] − [12] colors, the [12] − [25] colors of the two samples of stars are nearly identical. The average value of $F_\nu(25\ \mu m)/F_\nu(12\ \mu m)$ from the non–color-corrected *IRAS* fluxes for the stars brighter than $m_K = 5.0$ mag listed in Table 1 is 0.31. The average value for the same quantity for the stars in the solar neighborhood listed by Claussen *et al.* is 0.34.

It is clear from Figure 3 that some of the stars in the local neighborhood are losing much more mass than the "typical" value of $\sim 2 \times 10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$. However, occasionally even low-metallicity carbon stars have high mass-loss rates. That is, carbon stars losing large amounts of mass are pre–planetary nebulae (Zuckerman *et al.* 1977), and carbon-rich planetary nebulae exist in the Magellanic Clouds (Maran *et al.* 1982), where the metallicity is known to be lower than in the solar neighborhood.

V. DISCUSSION

The space density of carbon stars appears to remain constant at least to 3 kpc beyond the Sun in the anticenter direction. This result is quite striking because there is a substantial decrease in the total number density of disk stars over this same distance. Therefore, the relative fraction of carbon stars apparently increases in the anticenter direction.

This increase in the relative number of carbon stars in the anticenter direction has been suspected for many years (Blanco 1965), and is consistent with other current data for the numbers of carbon stars. In regions of high metallicity, such as the Galactic bulge, there are relatively few carbon stars (Blanco, McCarthy, and Blanco 1984; Frogel and Whitford (1987) while in regions of low metallicity, such as the Magellanic Clouds, the relative number of carbon stars is quite high (Cohen *et al.* 1981).

According to Pagel and Edmunds (1981), the metallicity gradient in the solar neighborhood (-0.05 dex kpc^{-1}) is such that at 3 kpc from the Sun the metallicity should have decreased to about 0.7 of the solar value. This drop in metallicity could significantly enhance the probability that a star will evolve into a carbon star (see Iben and Renzini 1983).

There are relatively more carbon stars in the anticenter direction, either because more stars evolve into carbon stars in the solar neighborhood or because stars spend a longer duration in the carbon star phase. In the solar neighborhood, at least half of the stars that die and become planetary nebulae are carbon-rich (Zuckerman and Aller 1986). Therefore, it is plausible that the explanation for the increase in the total fraction of stars that are carbon stars in the anticenter direction is that the anticenter stars spend a longer time in this carbon-rich stage of their evolution. Claussen *et al.* (1987) argued that if most F stars on the main sequence become carbon stars, then the duration of this phase is about 10^5 yr. For the low-metallicity carbon stars, the duration of the carbon star phase might be $(2\text{–}3) \times 10^5$ yr. This lifetime as a carbon star is fully consistent with theory where it is predicted that a star spends more than 10^6 yr on the asymptotic giant branch (Iben and Renzini 1983).

VI. SUMMARY

There are three main results of our analysis:

1. The K-band extinction gradient in the anticenter direction is between 0.15 and 0.3 mag kpc^{-1} in the plane of the Milky Way.

2. In contrast to the total density of stars, the density of high-luminosity carbon stars apparently does not decrease in

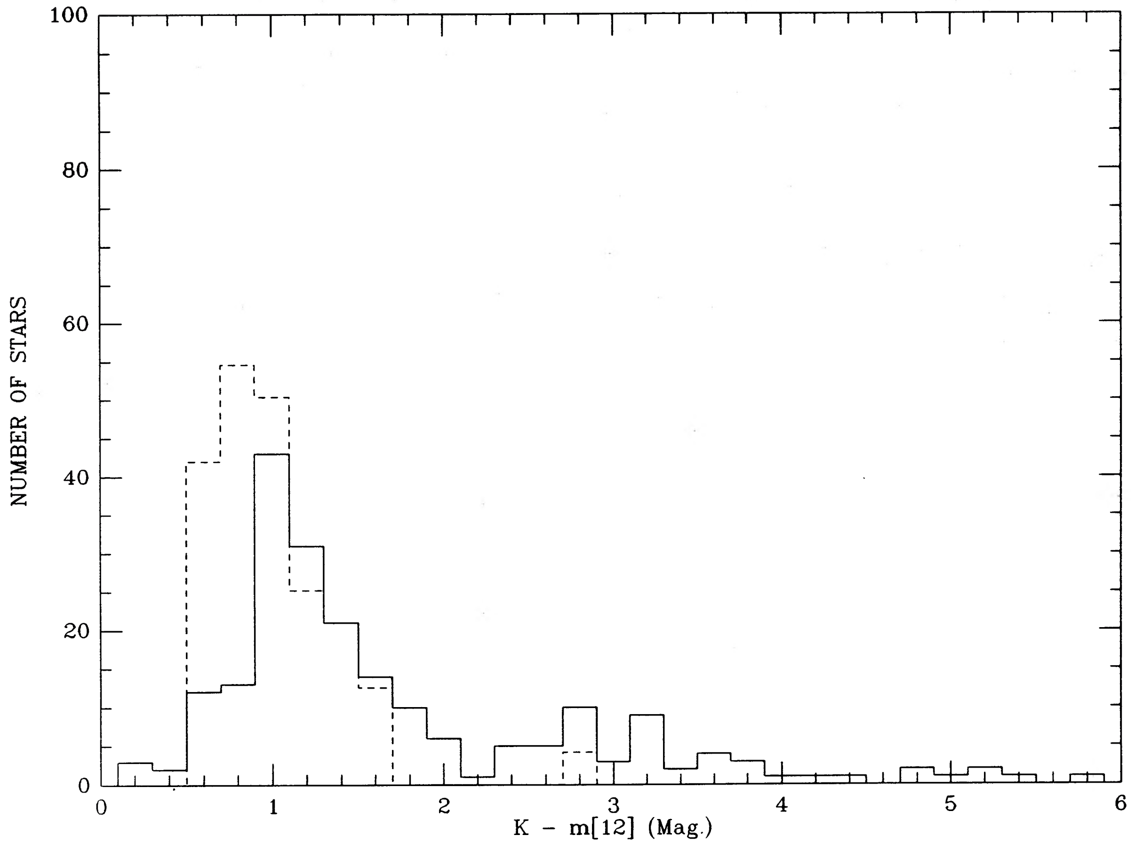

FIG. 3.—Histograms of the [$K - m(12)$] color of the stars in the solar neighborhood (*solid lines*) and in the anticenter region (*dashed lines*). To have a complete sample, we consider only stars with $4.0 < m_K < 5.0$ mag. The number of such stars in the anticenter region is scaled by a factor of 4.4, so that each histogram subtends the same area. We assume 0.15 K mag kpc^{-1} of extinction.

the anticenter region out to at least 3 kpc from the Sun. A plausible explanation for this result is that lower metallicity stars spend more time as carbon stars than do stars of solar metallicity.

3. The average mass-loss rates from high-luminosity carbon stars in the anticenter direction appear to be lower by a factor of 1.7 than for carbon stars in the solar neighborhood. This effect could be a consequence of the lower metallicity of these stars so that radiation pressure on dust is less effective in driving the mass outflows. Because the relative number of high-luminosity carbon stars increases while the mass loss from each individual carbon star may decrease, the net contribution of all carbon stars into the interstellar medium does not change drastically at anticenter distances greater than 3 kpc from the Sun.

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