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THE AGE OF THE LARGE MAGELLANIC CLOUD CLUSTER NGC 1953[1]

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ABSTRACT

NGC 1953 is a globular cluster in the Large Magellanic Cloud. A color-magnitude diagram (*C-M*) is fitted with appropriate isochrones which indicate that the age of the cluster is 250 ± 50 million years. The *C-M* diagram also suggests that this cluster may contain a number of Cepheid variables. Spectroscopic observations reveal that the most luminous asymptotic giant branch star in the cluster is an S star, thus observationally confirming that the third dredge-up mechanism does occur in stars with initial masses at least as large as 3.4 $M_\odot$. The spectrum of this AGB star also shows Balmer lines in emission, indicative of mass loss, and thus it is likely that the evolution of this star on the AGB will terminate before the transition from M star to C star is completed.

Subject headings: globular clusters: individual (NGC 1953) — Magellanic Clouds — stars: AGB and post-AGB — stars: evolution

1. INTRODUCTION

NGC 1953 is a $M_V = -7$ mag star cluster centrally located in the Large Magellanic Cloud (~ 1 kpc North of the optical center). It is intermediate age according to its integrated colors (van den Bergh 1981), corresponding to Searle, Wilkinson, & Bagnuolo's (1980, hereafter SWB) Class III (see Frenk & Fall 1982). As Magellanic Cloud star clusters are an important laboratory for testing our ideas on stellar evolution, we continue our photometric survey of these systems with an emphasis on establishing the age of the cluster (Mould 1991; Da Costa 1990).

In this respect, NGC 1953 is of special importance, since IR photometry (Mould & Aaronson 1982) has suggested that the brightest star in this cluster may be a carbon star. Such stars are rare in the (younger) SWB Type III clusters being predominantly found instead in the (older) SWB Type IV-VI clusters (Frogel, Mould, & Blanco 1990). The observed dearth of C stars on the AGB in the SWB Type III and younger clusters has been ascribed to either termination of the AGB evolution via mass loss prior to the onset of the third dredge-up mechanism, or to envelope burning in which the third dredge-up mechanism produces an excess of nitrogen, rather than carbon, in the surface layers. However, regardless of which explanation is correct, it is clearly important to establish observationally the youngest age, and thus the highest turnoff mass, for which the third dredge-up process unequivocally occurs on the asymptotic giant branch.

2. PHOTOMETRY

The 4 m telescope at CTIO was used to observe the cluster at prime focus. The scale of the instrument is 0″.6 pixel^{-1}. Exposures of the cluster were made through a Johnson B filter and a Kron-Cousins R imaging on to a 512 × 320 RCA CCD. Conditions were photometric, and the seeing was 1″.5 FWHM. Three 1000 s blue exposures were taken on 1984 November 25 together with 8 300 s red exposures. Details of the data processing and calibration are provided by Mould, Jensen, & Da Costa (1992).

Figure 1 (Plate 20) shows the combined blue frame. Point-spread-function photometry was carried out using the ALLSTAR routine of DAOPHOT II (Stetson 1987, 1991). Table 1 records the colors, magnitudes and coordinates of stars in a central 80″ field. Figure 2 is an enlargement of Figure 1 and serves to identify these stars. Three stars brighter than $R = 16.0$ mag are indicated with a colon in Table 1, because their magnitudes are affected by saturation.

3. THE COLOR-MAGNITUDE DIAGRAM

The noteworthy features of the *C-M* diagram in Figure 3 (which is prepared from Table 1) are a main-sequence turnoff at $R \sim 17$ mag and a fairly sparsely populated core helium burning loop in the magnitude immediately above the turnoff and extending from $B-R$ 0.5 to 2.0 mag. The blue loop crosses the instability strip and some of these stars are likely to be Cepheids. It would be desirable to monitor the cluster in order to identify them.

Before we can fit isochrones, we must discuss the reddening and metallicity of NGC 1953. According to Mathewson & Ford's (1982) map of the Magellanic Stream the cluster lies in a region with $\sim 2 \times 10^{21}$ H I atoms cm^{-2} either in front of it or behind it, or both. According to Sauvage & Vigroux (1991) this corresponds to $E(B-V) = 0.09$. Foreground reddening for the LMC can be taken as $E(B-V) = 0.07$. To correspond to $E(B-V) = 0.16$, we adopt values of $E(B-R) = 0.23$ and $A_R = 0.28$ mag for the reddening. There is no information available to provide a specific metallicity estimate for NGC 1953. Based

[1] Based on data obtained at Cerro Tololo Inter-American Observatory CTIO is part of NOAO which is operated by AURA, Inc., for NSF.

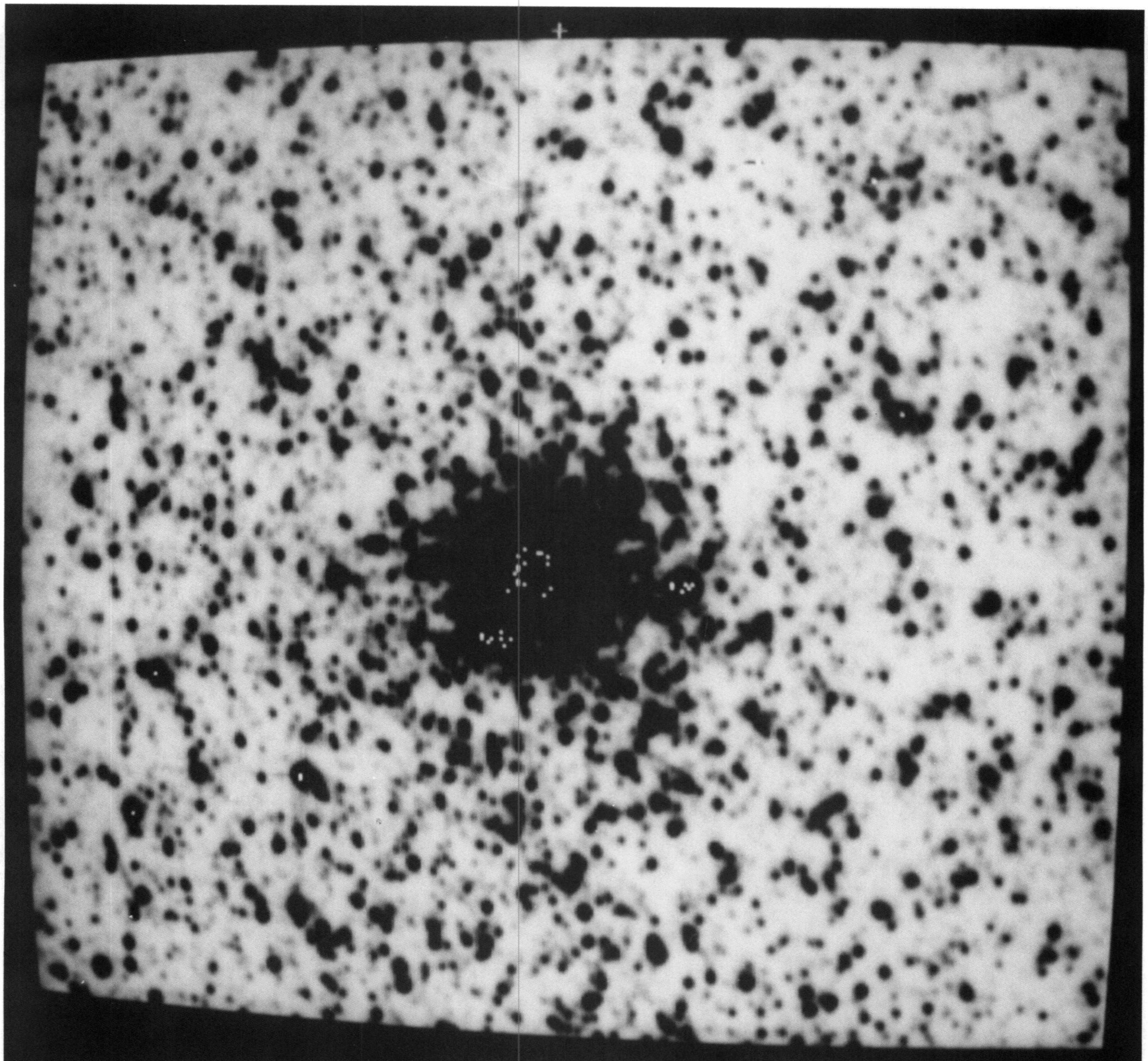

FIG. 1.—Full 3′ × 5′ image of the cluster north is up, and east is to the left

MOULD et al. (see 416, 582)

TABLE 1

PHOTOMETRY OF STARS IN NGC 1953

#	x	y	B-R	R
1	178	232	2.14	15.38
2	111	261	2.15	15.59
3	157	245	1.72	15.96
4	85	276	2.24	16.00
5	132	274	0.94	16.03
6	153	250	1.20	16.04
7	137	236	0.60	16.05
8	126	244	1.81	16.19
9	127	215	1.45	16.25
10	137	241	0.92	16.27
11	151	242	1.11	16.44
12	142	284	1.74	16.46
13	97	215	1.20	16.47
14	120	245	0.42	16.45
15	161	226	-0.15	16.55
16	131	247	0.46	16.57
17	195	257	1.44	16.68
18	148	238	0.53	16.76
19	149	250	0.63	16.78
20	157	240	1.35	16.80
21	98	234	1.67	16.85
22	122	203	1.33	16.88
23	105	225	1.49	16.91
24	113	281	1.44	16.91
25	151	264	0.75	16.91
26	83	226	-0.03	16.98
27	99	219	1.51	17.07
28	170	212	1.85	17.12
29	101	209	1.61	17.16
30	116	278	1.90	17.19
31	139	281	0.13	17.16
32	175	302	1.62	17.18
33	169	263	0.35	17.22
34	95	219	-0.12	17.22
35	124	186	0.24	17.26
36	93	282	1.98	17.35
37	121	233	0.07	17.31
38	119	257	0.19	17.36
39	92	276	1.19	17.41
40	185	260	1.47	17.46
41	158	229	0.13	17.50
42	155	234	0.42	17.57
43	184	282	1.47	17.61
44	115	248	1.54	17.66
45	165	287	1.95	17.68
46	150	287	1.74	17.72
47	114	273	0.12	17.70
48	163	276	0.10	17.78
49	163	296	0.63	17.80
50	112	307	1.66	17.83
51	142	270	0.26	17.81
52	138	292	0.55	17.85
53	151	225	0.17	17.84
54	145	302	0.06	17.84
55	158	267	0.15	17.88
56	151	269	-0.06	17.92
57	116	258	0.08	17.94
58	93	287	1.19	17.98
59	154	226	0.12	17.98
60	157	259	0.24	18.03
61	171	288	1.52	18.07
62	161	236	0.16	18.05
63	193	269	0.30	18.06
64	155	274	-0.08	18.07
65	110	251	0.01	18.08
66	100	241	0.04	18.08
67	126	235	0.09	18.09
68	131	223	0.18	18.09
69	169	248	0.12	18.09
70	162	244	0.80	18.14
71	111	245	-0.03	18.12
72	83	266	0.18	18.17
73	142	204	0.51	18.19
74	81	260	1.58	18.24
75	153	296	0.33	18.24
76	118	291	0.13	18.25
77	133	227	0.04	18.25
78	169	237	0.16	18.27
79	204	239	0.17	18.28
80	175	216	-0.01	18.28
81	91	244	0.06	18.28
82	109	232	-0.07	18.34
83	143	276	-0.06	18.39
84	149	281	0.20	18.40
85	200	272	1.60	18.46
86	203	247	1.69	18.46
87	102	295	0.14	18.43
88	152	314	1.04	18.45
89	164	252	0.15	18.44
90	127	224	1.39	18.46
91	151	212	0.15	18.46
92	137	270	-0.12	18.48
93	129	307	1.42	18.51
94	164	256	-0.21	18.48
95	178	254	1.96	18.52
96	172	198	1.21	18.51
97	188	277	1.08	18.53
98	160	251	0.16	18.50
99	119	207	1.14	18.54
100	88	264	1.48	18.56
101	97	245	0.22	18.54
102	188	226	1.29	18.56
103	162	202	0.16	18.58
104	89	222	0.10	18.59
105	151	313	0.86	18.61
106	106	245	1.30	18.63
107	106	282	0.04	18.66
108	122	211	0.15	18.67
109	107	264	1.03	18.70
110	118	212	1.56	18.72
111	166	282	1.02	18.72
112	175	244	1.04	18.75
113	107	277	0.04	18.72
114	164	269	1.27	18.82
115	146	203	0.09	18.86
116	169	278	0.09	18.88
117	120	302	0.43	18.89
118	13	280	0.31	18.91
119	76	255	0.29	18.91
120	113	298	1.95	18.98
121	136	299	0.73	18.96
122	91	236	0.11	18.94
123	98	257	1.03	18.97
124	152	284	0.37	18.98
125	184	243	0.52	19.00
126	110	210	-0.06	19.02
127	141	188	0.26	19.03
128	112	237	-0.12	19.10
129	149	232	-0.24	19.10
130	165	210	0.46	19.11
131	135	199	0.38	19.12
132	191	247	0.22	19.14
133	93	207	0.08	19.16
134	205	257	0.07	19.21
135	121	190	0.19	19.21
136	117	196	0.48	19.23
137	100	274	0.03	19.24
138	111	236	-0.27	19.24
139	124	199	0.72	19.26
140	110	256	-0.22	19.28
141	99	299	0.21	19.28
142	157	255	0.96	19.31
143	151	292	0.55	19.32
144	89	267	0.06	19.34
145	180	267	0.19	19.37
146	192	228	0.24	19.36
147	110	302	0.32	19.40
148	118	194	0.18	19.42
149	181	248	0.27	19.53
150	109	285	0.64	19.55
151	129	298	0.99	19.58
152	182	217	0.18	19.59
153	114	216	0.28	19.61
154	195	285	0.57	19.62
155	199	236	0.42	19.63
156	189	245	0.25	19.64
157	126	280	0.16	19.64
158	87	259	-0.07	19.65
159	173	250	-0.60	19.70
160	90	259	0.69	19.72
161	185	290	0.06	19.73
162	123	299	-0.10	19.73
163	131	195	0.60	19.76
164	76	237	0.50	19.77
165	183	237	0.42	19.78
166	106	238	0.39	19.82
167	127	284	1.63	19.85
168	175	294	0.28	19.83
169	170	296	2.04	19.88
170	179	199	0.44	19.86
171	132	291	0.52	19.88
172	106	291	0.08	19.87
173	111	219	-0.38	19.86
174	135	285	-0.11	19.89
175	80	271	0.37	19.91
176	86	251	0.19	19.92
177	193	219	0.60	19.93
178	201	253	0.39	19.94
179	171	255	0.39	19.96
180	181	299	0.17	19.98
181	181	277	0.46	20.00
182	113	289	0.47	20.04
183	152	200	0.49	20.07
184	180	205	0.48	20.07
185	111	191	0.84	20.11
186	176	262	0.25	20.10
187	188	207	0.96	20.11
188	175	283	0.23	20.18
189	95	292	0.22	20.19
190	104	299	0.13	20.19
191	173	240	0.79	20.24
192	124	275	0.29	20.23
193	196	244	0.60	20.25
194	168	304	0.58	20.26
195	140	195	0.50	20.30
196	139	228	-0.27	20.32
197	128	293	0.75	20.34
198	200	250	0.39	20.34
199	128	206	-0.51	20.33
200	93	294	0.06	20.37
201	147	192	0.48	20.40
202	134	192	0.94	20.42
203	175	194	0.63	20.41
204	116	201	0.67	20.42
205	147	188	0.56	20.43
206	153	207	0.74	20.46
207	177	281	0.29	20.46
208	102	266	-0.09	20.48
209	154	303	0.24	20.51
210	196	239	0.20	20.52
211	93	252	0.58	20.54
212	176	211	0.19	20.53
213	193	212	1.12	20.57
214	91	232	0.54	20.61
215	194	251	0.48	20.63
216	120	306	0.17	20.63
217	78	246	0.70	20.66
218	187	231	0.35	20.69
219	142	209	0.74	20.72
220	100	201	0.98	20.76
221	137	305	0.52	20.79
222	115	228	-0.10	20.79
223	73	249	1.41	20.83
224	179	289	0.31	20.84
225	151	301	-0.03	20.86
226	129	290	1.31	21.02
227	99	271	-0.03	21.04
228	112	206	0.20	21.08
229	197	263	0.31	21.12
230	104	202	0.87	21.19
231	166	198	0.56	21.29
232	181	221	-0.19	21.34
233	77	228	0.40	21.54
234	103	248	3.15	21.60
235	184	213	0.82	21.58
236	170	191	1.53	21.81

on what is known of the age-metallicity correlation for the LMC (e.g., Olszewski et al. 1991), we adopt [Fe/H] $= -0.4$ in the usual notation.

We fitted isochrones at a distance modulus $(m-M)_0 = 18.5$ mag (Caldwell & Laney 1990). The isochrone in Figure 3 is from the calculations by Bertelli, Bressan, & Chiosi (1990), who adopt a helium abundance $Y = 0.25$ and a Reimers' (1975) mass-loss parameter $\eta = 0.35$. The age of the isochrone is 250 Myr. As shown in Figure 3, an age of 250 million years provides a satisfactory fit to the data. Uncertainties in distance modulus, reddening, chemical composition, and the extent of convective overshooting, discussed in more detail by Mould et

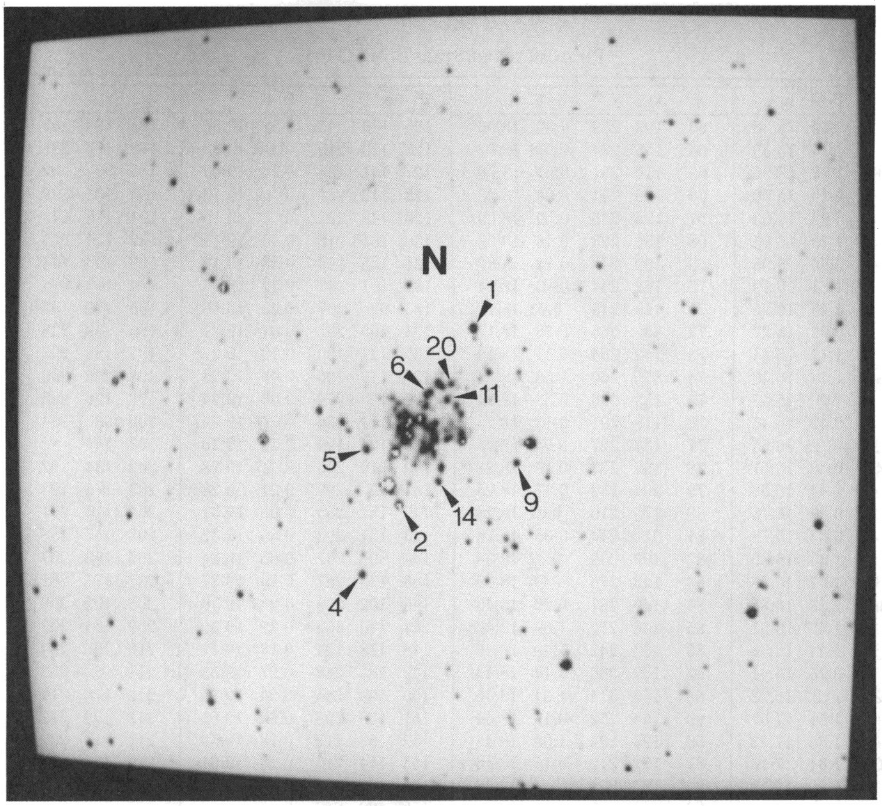

FIG. 2.—Central 2′ × 2′ of the cluster star numbers refer to Table 1

al. (1992), combine to make up a ±20% uncertainty in this estimate.

In previous papers we have considered isochrone fits at both a short distance modulus for the LMC (18.2 mag) and a long modulus (18.7). Figure 4 shows that a 200 Myr isochrone has a 0.4 mag brighter turnoff. The long modulus would therefore yield an age 10% younger and the short modulus 15% older than inferred above.

It is evident from Figure 1 that NGC 1953 lies in a crowded field. To verify that the turnoff stars at $R = 17$ are cluster

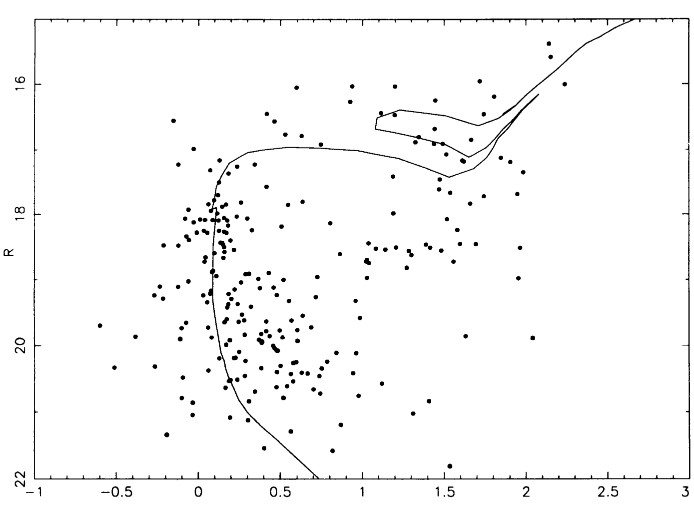

FIG. 3.—*C-M* diagram of the cluster within 67 pixels of the cluster center. The superposed isochrones are 250 Myrs, $Z = 0.008$. A distance modulus of 18.5 was adopted.

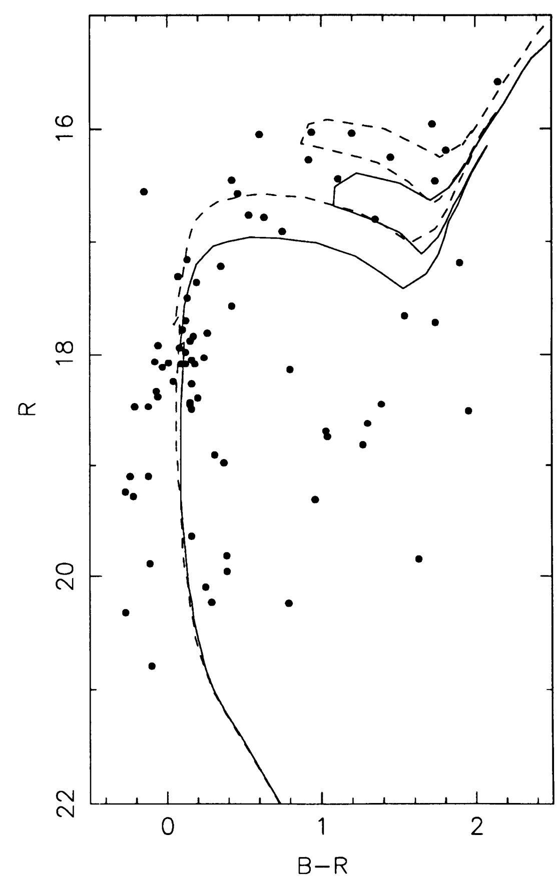

FIG. 4.—*C-M* diagram of the cluster within 40 pixels of the cluster center. The superposed isochrones are 200 (*dashed curve*) and 250 (*solid curve*) Myrs, $Z = 0.008$. A distance modulus of 18.5 was adopted.

members we show Figure 5, the *C-M* diagram for stars *further* than 48″ from the cluster center. Counting main-sequence stars in the *R* magnitude interval (17, 18) in Figure 5, we estimate less than 10% contamination by field stars in Figure 3 in that magnitude interval. Note also that the turnoff is similarly located in Figure 4, which is drawn from a more concentrated cluster sample, and that the red stars at $R = 18.5$ in Figure 3 (less evident in Fig. 4) are clump stars from the ubiquitous 1–3 Gyr stellar population making up the field of NGC 1953.

4. THE ASYMPTOTIC GIANT BRANCH

Lloyd Evans (1980) was first to survey the cluster for highly evolved red stars. He found two, but these proved to be fainter than -4 in M_{bol}. Mould & Aaronson (1983) located a third star, close to the cluster center with very red 1–2 μm colors and identified it as a probable carbon star. It is the brightest star known in the cluster with $M_{bol} = -4.5$ for the distance modulus adopted here.

A spectrum of this star was obtained at the 4.0 m telescope of Cerro Tololo Inter-American Observatory on the night of 1993 January 27. The night was clear and seeing was 1″.5. A 1000 s exposure was taking with the Folded Schmidt + Tek1024 camera on the RC spectrograph, using grating KPGL2. The spectrum covers 3600–7000 Å, with 6–9 Å resolution from the blue to red. These observations were taken as a fill-in program and minimal calibrations were available. The spectrum is shown in Figure 6, and shows that NGC 1953 MA 3 is not a carbon star, but an S star, with Hα and Hβ in emission. Strong TiO bands are present at 4955, 5450, and 5850 Å, but the ZrO band head at 6472 Å is characteristic of S stars. Classification on the system of Keenan & Boeshaar (1980) is impossible at our resolution because of the strong wings of Hα, but comparison with the sequence of M through S stars in NGC 1783 (Lloyd Evans 1984) leaves no doubt about the identification. Balmer lines in emission are uncommon in LMC AGB stars (Reid & Mould 1985). This suggests the star is a Mira variable.

The integrated spectral light from the cluster is also visible along the slit and shown in Figure 7. Strong Balmer absorption is evident and may contaminate the MA 3 spectrum. Balmer emission at the LMC velocity is also evident along the slit, away from the cluster center.

With an age of 250 ± 50 Myr, NGC 1953 is one of the youngest clusters to contain an AGB star with evidence of third dredge up activity (Iben & Renzini 1983). A rival cluster for this distinction is NGC 2031 (Mould, Xystus, & Da Costa

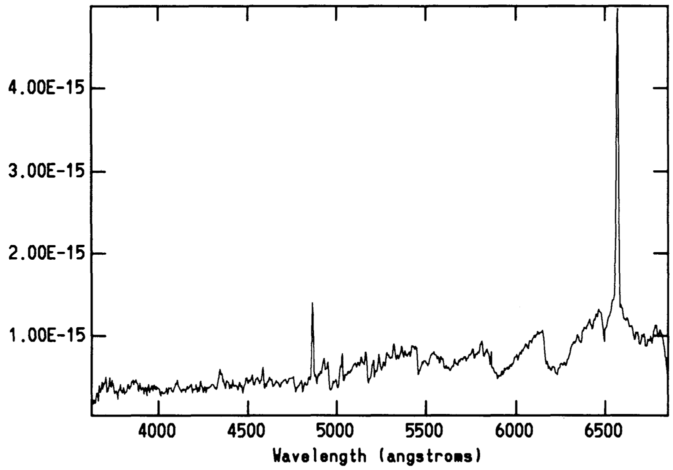

FIG. 6.—Spectrum of Mould & Aaronson (1983) star 3 in NGC 1953. The resolution varies from 6 Å at 3700 Å to 9 Å at 6700 Å. A scaled spectrum of the integrated cluster light has been subtracted to remove the A star contamination.

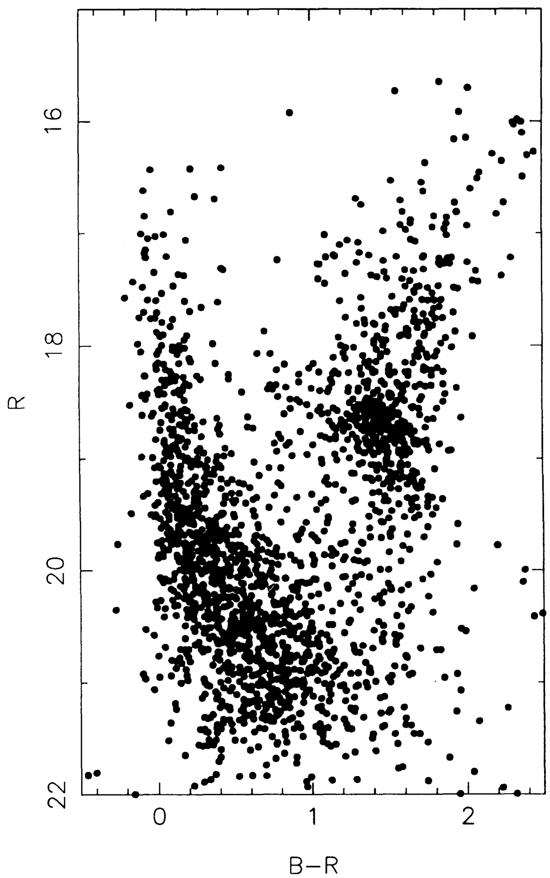

FIG. 5.—*C-M* diagram of the field outside 80 pixels of the cluster center

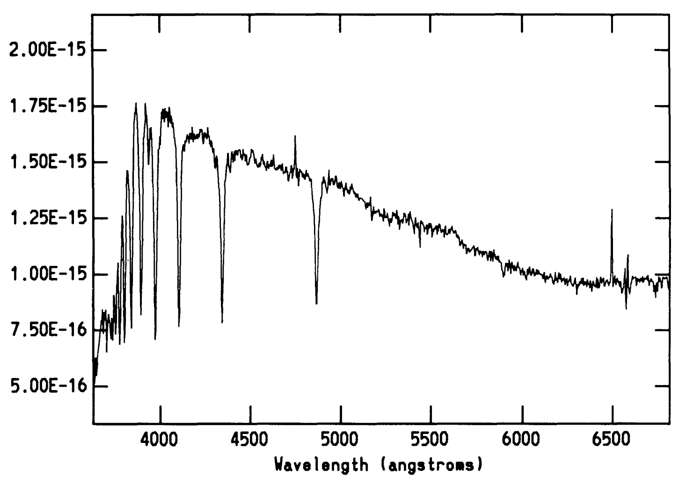

FIG. 7.—Spectrum of the integrated light of NGC 1953

1993) with an age of 140 ± 20 Myr, but no spectrum is yet available of the candidate carbon star NGC 2031-J.[2]

Younger clusters such as NGC 1866 (age 100–200 Myrs according to Brocato et al. 1989 and Chiosi et al. 1989) contain only M stars on the AGB. (We note that there is some doubt about the classification of the candidate carbon star in NGC 1850; Frogel, Mould, & Blanco 1990). After NGC 1953, the next oldest cluster with a confirmed population of thermally pulsing AGB stars is the SWB class III-IV cluster NGC 2209. That cluster contains two carbon stars and has an age of ~ 750 Myr (Da Costa, Mould, & Xystus 1993). The confirmation that NGC 1953 contains a thermally pulsing AGB star is thus a matter of some importance, since it is unresolved at the present time whether the upper initial mass limit for carbon stars is determined by envelope burning or mass loss (see the discussion following Mould 1991). Envelope burning (Sackman & Boothroyd 1992; Blocker & Schonburner 1992; Renzini & Voli 1980) is a process whereby carbon produced in the third dredge-up is burned to nitrogen before mixing to the surface. It is expected to be confined to stars of large core mass. Alternatively, mass loss may be responsible for terminating AGB evolution before dredge-up in clusters younger than approximately a billion years (Aaronson & Mould 1985).

[2] We recently obtained photometry of NGC 2031-J at Las Campanas Observatory. With $K = 10.2$ and $J-K = 1.23$, the bolometric magnitude is -5.4, if it is a carbon star.

If NGC 1953 MA 3 is a Mira, it probably has only 10^4 yr to live on the AGB and therefore will not complete its transition from M star to carbon star. Mass loss (as evidenced by the emission lines) will win this race. It thus seems plausible that NGC 1953, where the turnoff mass is $\sim 3.4\ M_{\odot}$, occupies a pivotal position: in younger clusters mass loss truncates the AGB before third dredge-up begins, while in older clusters third dredge-up can progress sufficiently to complete the transition to $C > O$ in the surface layers. On the other hand, it is possible that some of the carbon produced in third dredge-up star is being burned at the base of its envelope, and that this is slowing the star's transition to a carbon star. However, there is no evidence in the form of detectable Li I 6707 Å for strong envelope burning in this star (Smith & Lambert 1990; Boothroyd & Sackman 1992). To settle these questions we need to study 10^8 yr old clusters, such as NGC 1953 and 2031, more closely.

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