THE ASTROPHYSICAL JOURNAL, **234**: 513–520, 1979 December 1

FURTHER SPECTROSCOPIC EVIDENCE BEARING ON THE M22–ω CENTAURI COMPARISON

JAMES E. HESSER[1]
Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics
AND
GRETCHEN L. H. HARRIS[1]
University of Waterloo
Received 1979 April 30; accepted 1979 June 15

ABSTRACT

Spectroscopic observations made at CTIO of stars from the giant-branch tip to well below the horizontal-branch level on the subgiant branch of M22 ($\alpha = 18^h33^m.3$, $\delta = -23°58'$ (1950); $l = 9°$, $b = 8°$) provide identification of 15 new radial-velocity members, including a second giant CH star (IV-24) and a possible subgiant CH star (III-32). In general, M22 stars show a marked range of CN strengths. These and other recent results seem consistent with the suggestion that M22 may share, albeit in a weaker form, some of the distinguishing anomalies of ω Cen.

Subject headings: clusters: globular — stars: abundances — stars: late-type — stars: Population II

I. THE PROBLEM

In the course of their analysis of DDO intermediate-band photometry of evolved globular cluster stars, Hesser, Hartwick, and McClure (1976, 1977; hereafter HHM76, HHM77) suggested that NGC 6656 = M22 may share, to a lesser degree, some of the otherwise unique properties of NGC 5139 = ω Cen. This comparison was based upon four main characteristics: (a) DDO photometry showing a wide range of both the general metal and CN indices for stars lying on or near the giant branch in Arp and Melbourne's (1959) color-magnitude diagram (CMD)—a property limited in HHM's 17 cluster sample to ω Cen and M22 alone (cf. also Freeman and Rodgers 1975; Norris and Bessell 1975; Lloyd Evans 1977; Butler, Dickens, and Epps 1978); (b) the presence of two Ba stars (Mallia 1976) and a probable CH star (HHM77)—again a property limited (at that time) to M22 and ω Cen (Harding 1962; Dickens 1972; Wing and Stock 1973; Bond 1975; Norris and Bessell 1977); (c) the M22 CMD arrays then available, which appeared to have an intrinsic scatter reminiscent of the "wide giant-branch" phenomenon peculiar to ω Cen (Woolley *et al.* 1966; Cannon and Stobie 1973); and (d) an apparent flattening of both clusters, which in the case of ω Cen is interpreted as indicating rotation of the cluster as a whole (Lindsay 1956; Harding 1965).

Subsequent investigations examining the suggested similarities between M22 and ω Cen have produced a decidedly ambiguous situation. For instance, previous CMDs have shown large scatter, as well as a morphological anomaly that the observed slope of the giant branch implied a relatively high metal abundance, while the rather blue horizontal branch implied a much lower metal abundance. The lower metal abundance implied by the horizontal branch is in accord with the RR Lyrae ΔS (Butler 1975) and Washington photometry (Canterna 1975) values for [Fe/H], −1.8. Now a new CMD by Alcaino (1977), reaching to about 1 mag below the horizontal branch, shows scatter only marginally reminiscent of ω Cen. Moreover, he finds a Hartwick (1968) $S \sim 5.3$ for the slope of the M22 giant branch, implying an [Fe/H] ~ -2 and thus confirming Lloyd Evans's (1975) result and apparently removing the aforementioned discrepancies in metallicity estimates. Lloyd Evans's (1978) analysis of recent near-infrared photometry by Eggen (1977) also suggests that the scatter in the M22 CMD is less than that of ω Cen and provides little evidence for similarities in color indices between giant stars of the two clusters. In addition, he (Lloyd Evans 1978) has determined that three of HHM's (1977) four stars having small ultraviolet excesses (i.e., the most metal-rich stars in their sample) are radial-velocity *non*members, thereby apparently reducing the range of metallicities inferred from the DDO photometry. Provided that differential reddening is low (cf. HHM77; Hesser 1976), elimination of radial-velocity nonmembers decreases but does *not* eliminate the tendency for M22 stars to show greater dispersion in the two DDO metallicity indices than do stars in comparably metal-poor clusters (cf. HHM77, Fig. 1*e*). Furthermore, McClure and Norris (1977) have spectroscopically confirmed the nature and cluster membership of the mild CH star photometrically identified by HHM77 [Arp and Melbourne (1959) number III-106]. [Mallia (1978) has recently

[1] Visiting Astronomers, Cerro Tololo Inter-American Observatory, which is operated by AURA, Inc., under contract AST 74-04128 with the US National Science Foundation.

pointed out that its C_2 bands are very weak and suggests that III-106 may be more like a Ba II star than a classical halo carbon star.] Despite systematic searches (Bond 1978) and numerous spectroscopic studies of hundreds of globular cluster giant stars, M22 and the similarly flattened cluster M55 (Menzies and Lloyd Evans, private communication; see also McClure and Norris 1977; McClure 1978) are the only globulars other than ω Cen presently known to possess CH or Ba II stars.

Clearly it is important to establish the extent to which stars in M22 may share the abundance peculiarities found in ω Cen. In addition, the problem has acquired even wider potential relevance following Freeman's (1978) comparison of the ω Cen characteristics with those of much more distant dwarf spheroidal and elliptical galaxies. It is the purpose of this paper to present radial velocity and qualitative line-strength information based on data obtained in 1978 July with the image-tube spectrographs on the 1 m (Yale) and 4 m telescopes at the Cerro Tololo Inter-American Observatory (CTIO). Forthcoming papers will discuss these and future observations in terms of quantitative abundance determinations and spectral classifications.

II. OBSERVATIONS

The program stars were selected from an uncalibrated CMD by Hartwick and Hesser (1979) based upon measurements of ~500 stars on four plates in both V and B, and upon measurements of an additional sample of ~200 fainter stars on one plate pair. Candidates for spectroscopic observation were chosen at all magnitude levels, from the turnoff region to higher luminosities, *only* if their images on deep 1 m and 4 m telescope plates suggested they could be observed without crowding problems. This is especially crucial in a cluster like M22 where crowding is generally severe. (Each field observed on the 4 m was also reexamined at the telescope with the integrating television viewing system in order to confirm the absence of contaminating stars.) The location of the observed stars within the CMD may be seen in Figure 1. As Hesser and Hartwick (1977) point out, the question of zero point and scale errors in available B, V photometry for M22 is unsettled, and there is still no single source of values obviously to be preferred. Consequently, we have collected in Table 1, as a function of increasing D plate iris reading ($\propto V$ magnitude),

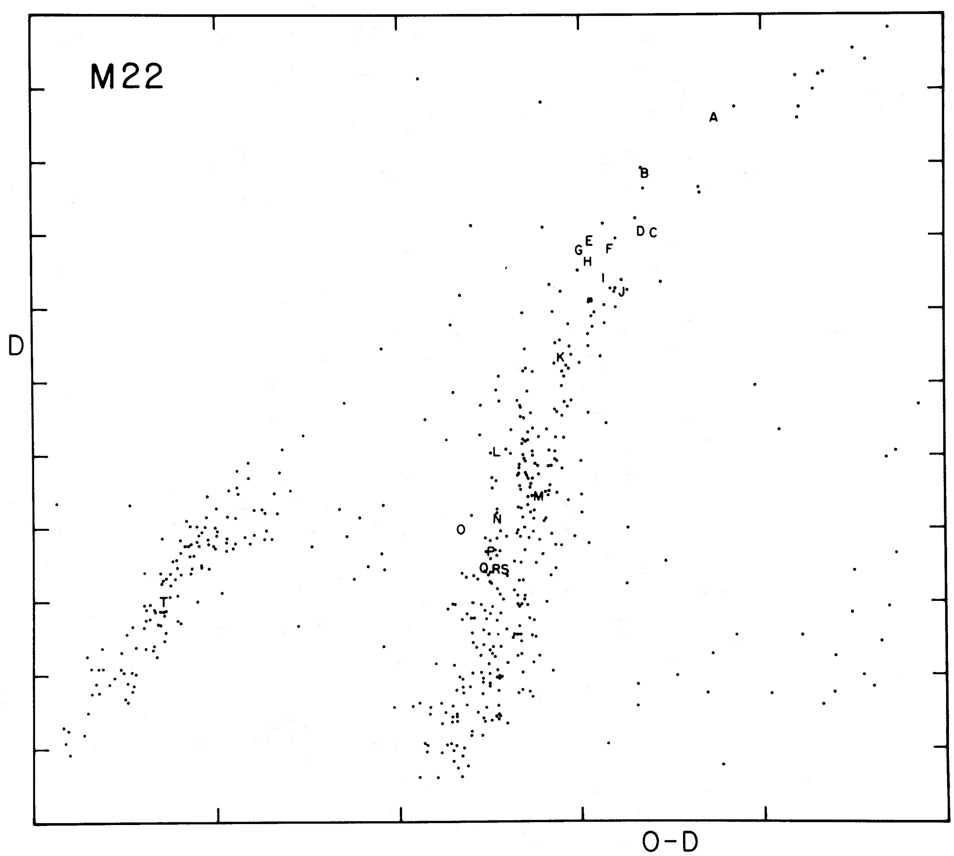

FIG. 1.—An instrumental color-magnitude array for M22 based upon measures of four plate pairs (Hartwick and Hesser 1979). The ordinate is the iris reading from the "D" ($\propto V$) emulsion plate, and the abscissa is the difference between the iris readings from the "O" and "D" ($\propto B - V$) emulsion plates. Letter symbols represent stars for which spectra were obtained in this program —see Table 1 and Fig. 2. Star "C" = III-106 was not included in the iris measurements and is placed in the figure using the values for it and other stars by Alcaino (1977).

TABLE 1

Photometric Data for the Spectroscopically Observed M22 Stars

IDENTIFICATION AM*	A*	HH*		V (mag) AM	LE	A	P.E.*	HH	B-V (mag) AM	LE	A	P.E.	HH	⟨V⟩†	⟨B-V⟩†	r(′)
I-92	1-78	1907	A	11.47		11.47	11.61	11.44	1.61	1.55	1.69	1.48	1.54	11.52	1.58	2.5
I-36		1605	B	11.79				11.75	1.55	1.39			1.33	11.79	1.47	1.4
III-106	3-59		C	12.40		12.19	12.19		1.30	1.44	1.42	1.49		12.26	1.41	4.6
III-33	1-40	6807	D	12.24		12.16		12.19	1.42	1.39	1.36		1.31	12.20	1.39	2.3
I-98		2811	E	12.34			12.40	12.27	1.26	1.32		1.27	1.20	12.37	1.28	2.4
III-47		5707	F	12.24				12.28	1.44	1.31			1.25	12.24	1.38	2.2
(I-106)‡		1708	G		12.52			12.33		1.21			1.24	(12.33)	(1.24)	2.2
IV-67		8805	H	12.39				12.39	1.34	1.30			1.19	12.39	1.32	2.2
II-23	1-3	3807	I	12.56		12.52		12.53	1.29	1.34	1.23		1.24	12.54	1.29	2.5
IV-24		7703	J	12.59				12.63	1.42	1.36			1.28	12.59	1.39	1.9
II-44	1-17	4807	K	12.98		13.02		12.99	1.20	1.19	1.15		1.16	13.00	1.18	2.5
III-30		6610	L	13.63				13.54	1.14				0.98	13.63	1.14	1.8
III-32		6811	M	14.05				13.84	1.05				1.08	(13.84)	(1.08)	2.4
IV-52	1-51	7906	N	14.04		14.08		14.01	1.12		1.03		0.99	14.06	1.075	2.6
IV-29	1-47	7904	O	14.13		14.15		14.09	1.10		0.92		0.91	14.14	1.01	2.6
		8909	P					14.25					0.98	(14.25)	(0.98)	2.7
IV-54		7907	Q	14.43				14.35	1.06				0.96	(14.35)	(0.96)	2.7
		1809	R					14.39					1.00	(14.39)	(1.00)	2.4
III-11§		5601	S	13.16	14.03			14.39	2.00	1.33			0.99	14.03	1.33	1.8
IV-26		7803	T	14.55				14.44	0.20				0.28	14.55	0.20	2.2

(FOOTNOTES TO TABLE 1)

*Photographic photometry AM = Arp and Melbourne (1959), LE = Lloyd Evans (1975), A = Alcaino (1977), HH = Hartwick and Hesser (1978); P.E. = photoelectric values from Hesser and Hartwick (1977) or Eggen (1977). A very useful cross-identification list can be found in Nemec (1978). In plate II of Arp and Melbourne (1959) HH1708 is located 2.6mm S of I-31 and is identified as I-106 by Lloyd Evans (1975); 1809 is 3.6 mm E of I-27; and 8909 is 3.0 mm E and 1.0 mm S of IV-69.

†Average of all measures but those of HH except where only the latter's preliminary values are available, in which case the average is their value placed within parentheses to emphasize its preliminary nature.

‡Lloyd Evans' (1975) extension of Arp and Melbourne's (1959) numbering system.

§A clerical or mis-identification error appears to have occurred in Arp and Melbourne (1959), as the star labeled III-11 is much fainter than its tabulated magnitude.

according to Figure 1, the various estimates of V and $B - V$ available for our program stars. We also made a crude calibration of the Hartwick and Hesser (1979) O-D diagram using photoelectric values of various observers in order to derive the approximate V and $B - V$ values attributed to "HH" in the table. The final column in Table 1 gives the approximate radial distance from the cluster center for each star.

Observations were obtained on the night of June 19/20 (plates E2120–E2124) and the half-night July 1/2 (plates E2125–E2126) with the Boller and Chivens spectrograph and RCA 33063 image tube on the 1 m Yale telescope at CTIO. The entrance slit was 100 μ wide (1″.9, projected $\sim$13 μ). Grating 26 (600 grooves mm^{-1}, 121 Å mm^{-1}) was used in first order at an angle of 8°40′ ($\lambda \sim$ 4500 Å). The image-tube transfer lens was used at f/1.4, and N_2 baked III-aJ plates (cut from 20 × 20 cm plates) were used. Widening of $\sim$0.5 mm was achieved with a sky-suppressor assembly whose slot was 9″.6 long on the sky. Spectra of several IAU radial-velocity standard stars, as well as of stars exhibiting various types of spectral peculiarities useful for comparison with the M22 observations, were also secured.

A different configuration was used for each of the two cloudy nights upon which spectroscopic observations were made at the 4 m telescope. Plates F1180–1185 were taken on 1978 July 4/5 by using the following parameters: entrance slit 160 μ (1″.1, projected $\sim$41 μ); decker 3 (50″, 1.95 mm on the plate), with trailing over $\sim\frac{1}{3}$ of its length; grating 400 (158 grooves mm^{-1}, 90.6 Å mm^{-1} in second order) with a Corning 9780 filter for second-order blocking longward of $\sim$3800 Å; grating tilt 62°.89 ($\lambda \sim$ 4000 Å); transfer lens setting f/1.4; and RCA 33063 dry-ice–cooled image tube. After the first night this configuration was abandoned because: (i) the exposure times seemed too long for the relatively low dispersion; (ii) the blocking filter transmitted first-order wavelengths greater than $\sim$7500 Å, so that much of the ultraviolet region of interest was lost to second-order interference; and (iii) the convolution of the declining filter transmission and the decreasing stellar flux in these late-type stars led to weaker exposures than desired below 4000 Å.

Plates F1186–1189 from the 4 m were secured during part of the night 1978 July 5/6 with a setup that differed from the above in the following ways; entrance slit 130 μ (0″.9, projected $\sim$34 μ); a new 632 grooves mm^{-1} first-order grating (46.7 Å mm^{-1}) tilted to 59°02 ($\lambda \sim$ 4300 Å); and, of course, no blocking filter. This higher dispersion grating seemed nearly as fast as the lower dispersion arrangement.

For all spectroscopic plates, calibrations were obtained with the small, portable projection sensitometer; the calibration plates were developed with the spectroscopic exposures.

III. RADIAL VELOCITIES

a) *Measurements*

All the spectra were measured on the Dominion Astrophysical Observatory's oscilloscopic measuring engine ARCTURUS and reduced with a program kindly made available by J. B. Hutchings. Ideally, appropriate wavelengths for each spectrograph configuration utilized should have been determined (cf. Petries 1962; Batten 1978). However, since the filter system on the CTIO 4 m spectrograph is a *post-slit* one, the spectrograph is not expected to be reliable for radial velocities when attempting to compare stars observed with and without, or with differing, neutral-density filters. Hence, the 4 m telescope velocity measurements for globular cluster stars are basically on the instrumental system, and reliance is placed on M22 stars that are known to be radial-velocity cluster members and an M15 star for identification of zero-point trends in the reduced radial velocities. On the other hand, observations with the 1.0 m telescope spectrograph of IAU radial-velocity standard stars (and other stars with velocities reliable for comparison with those from low-dispersion image-tube plates) seemed sufficient to justify attempting to deduce approximate wavelengths for the spectrograph as used. The iterative procedure used as its starting point the list of lines by Batten *et al.* (1971).

Our reductions suggest that on our 46.7 Å mm^{-1} plates a single line can be measured with a standard deviation of 20 km s^{-1}, while the 90.6 Å mm^{-1} or 121 Å mm^{-1} plates yielded internal single-line precisions of 30 km s^{-1}. Assuming that only seven lines enter into each mean velocity, the internal standard deviations should then be $\sim$8 km s^{-1} and $\sim$11 km s^{-1}, respectively. External errors may in part be estimated by examining the velocities shown in Table 2 for stars of known radial velocities observed at 121 Å mm^{-1}. The IAU velocity standards match the system with a standard deviation of $\pm$10 km s^{-1} as do, in fact, all the stars (except HD 176021) of Table 2. Four meas-

TABLE 2

STARS OF KNOWN RADIAL VELOCITY OBSERVED AT 121 Å mm^{-1}

HD/CPD	TYPE	PLATE*	n	v_r (CTIO)	v_r (REF)	Δ(CTIO-REF)	$\bar{\Delta}$	COMMENTS
26	CH	E2124	11	-216 km/sec	-213 km/sec	- 3 km/sec	- 3	
92588	sgk 1	E2125	18	29	43	-14	-14	IAU
107328	gk 1	E2120	17	34	36	- 2	6	IAU
107328	gk 1	E2120	19	40	36	4		IAU
107328	gk 1	E2120	19	37	36	1		IAU
107328	gk 1	E2125	16	57	36	21		IAU
122563	wk metal	E2121	6	- 1	- 25	24	23	
122563	wk metal	E2125	6	- 3	- 25	22		
126053	d G3	E2121	12	12	- 18	30	11	IAU
126053	d G3	E2121	13	- 9	- 18	9		IAU
126053	d G3	E2125	10	- 25	- 18	- 7		IAU
136202	d F6	E2121	6	85	53	32	3	IAU
136202	d F6	E2125	10	27	53	-26		IAU
157457	K 1	E2122	18	7	17	-11	-14	IAU
157457	K 1	E2125	13	- 16	17	-33		IAU
157457	K 1	E2125	16	- 8	17	-25		IAU
157457	K 1	E2126	17	30	17	13		IAU
165634	wk G	E2121	14	- 10	- 4	- 6	- 6	
171391	g G7	E2122	14	2	7	- 5	0	IAU
171391	g G7	E2122	16	2	7	- 5		IAU
171391	g G7	E2126	14	10	7	3		IAU
171391	g G7	E2126	14	15	7	8		IAU
176021	s.g. CH	E2122	10	160	106	54	54	ID questioned at telescope
203638	g K2	E2123	13	30	22	8	8	IAU
212943	s.g. K0	E2124	16	44	54	-10	-10	IAU
-62° 6195	s.g. CH	E2122	7	119	119	0	0	
Mean (IAU)± σ_i							- 1.2±	10.1
Mean (ALL)± σ_i							4.5±	18.2 [0.3±10.8]†

* Repeated plate numbers indicate more than one exposure per plate of a given star.
† The value in parentheses results from elimination of the HD 176021 observation.

urements of a bright star of known velocity with the 47 Å mm^{-1} plates gave a standard deviation of ± 2 km s^{-1} for a single v_r value. For the 96 Å mm^{-1} material no repeat measures of any star are available. While more data would have allowed a more thorough estimate to be made of errors, we feel confident that our derived velocities are of 20 km s^{-1} or better precision, which is adequate for our purpose.

b) *Results: M22*

Our heliocentric radial velocities for the M22 stars are summarized in Table 3, where the CTIO plate number (F = 4 m telescope, E = 1 m telescope) is followed by the exposure time in minutes within parentheses, then the number of lines contributing to the velocity; the rightmost column lists other velocity determinations known to the authors for the particular star. For reference, the radial velocity of M22 is -144 km s^{-1} (Mayall 1946; Joy 1949; Kinman 1959; Hesser and Shawl 1978).

From the seven M22 stars observed with the lowest dispersion we find an average velocity of -140 ± 6.8 km s^{-1} (standard deviation of the mean), while the standard deviation of an individual spectrum is 18 km s^{-1}.

The 4 m telescope 96 Å mm^{-1} spectra yield v_r values consistently more negative by 27 km s^{-1} than the Mayall-Kinman value, a problem whose origins may include the impossibility of independently determining appropriate wavelengths. (Hutchings *et al.* 1977 and Crampton, Hutchings, and Cowley 1978 also have observed the 4 m spectrograph, in other configurations, to give v_r values in error by -10 km s^{-1}.) Inspection shows that the two member stars in common with Lloyd Evans (1978) reflect the same offset from the -144 km s^{-1} cluster value as do the average of all stars observed in M22 at this dispersion. Also, star II-75 in NGC 7078 (M15) was observed following M22 on July 4/5 and its deduced v_r, -122 km s^{-1}, is also more negative than that cluster's firmly established value of -107 km s^{-1} (Mayall 1946; Kinman 1959; Joy 1949; Smith, Hesser, and Shawl 1976; Hesser and Shawl 1978). Finally, we note that no individual M22 v_r value differs from the mean by more than 1.7 standard deviations of an individual spectrum. Hence, we conclude that the v_r information for the nine stars observed at 90.6 Å mm^{-1} indicates that they are all cluster members.

For the 47 Å mm^{-1} plates, the situation is almost identical to that of the 96 Å mm^{-1} material. A comparable zero-point shift of -30 km s^{-1} is evident, and no stars deviate from the mean v_r determined from plates of that dispersion by more than 1.4 standard deviations.

In brief, then, we believe the radial-velocity values in Table 3 provide strong evidence for the membership in M22 of all 19 stars we observed, thus providing 15 newly certified members of the controversial cluster.

c) *Results: Field Stars*

Among the various field stars for which spectra were secured for use in the classification aspects of this program, 12 appear to lack v_r values. Our results from the 1 m telescope 121 Å mm^{-1} plates for those stars are given in Table 4.

IV. SALIENT SPECTRAL CHARACTERISTICS

Although definitive analysis of M22 must await observations of statistically more meaningful samples

TABLE 3

RADIAL VELOCITIES FOR M22 STARS

STAR	46.7 Å/mm PLATE NO.	n	v_r (km/sec)	90.6 Å/mm PLATE NO.	n	v_r (km/sec)	121 Å/mm PLATE NO.	n	v_r (km/sec)	OTHER v_r (km/sec)
I-92	F 1187 (88)	15	-179				E 2126 (81)	10	-148	
I-36				F 1183 (8)	8	-179				-133 (Lloyd-Evans 1978)
III-106							E 2121 (70)	11	-133	-160 (McClure and Norris 1977) -139 (Lloyd-Evans 1978)
III-33							E 2126 (65)	11	-160	
I-98	F 1187 (76)	13	-158	F 1182 (7)	12	-157	E 2121 (44)	7	-165	-139 (Lloyd-Evans 1978)
III-47							E 2122 (120)	8	-120	
I-106	F 1188 (20)	12	-180	F 1184 (11)	7	-141				
IV-67							E 2122 (75)	8	-120	
II-23							E 2126 (107)	10	-135	
IV-24	F 1188 (24)	15	-188	F 1184 (24)	8	-164				
II-44	F 1188 (33)	12	-159							-151 (Lloyd-Evans 1978)
III-30	F 1189 (52)	Too weak								
III-32	F 1189 (44)	11	-183							
IV-52				F 1182 (30)	8	-167				
IV-29				F 1183 (38)	7	-195				
8909				F 1183 (45)	9	-176				
IV-54				F 1183 (39)	7	-148				
1809				F 1184 (65)	6	-208				
III-11	F 1189 (105)	9	-172							
IV-26=7803	F 1189 (44)	5	-175							
Mean			-174			-171			-140	
σ_i			11			22			18	

TABLE 4

VELOCITIES FROM 121 Å mm^{-1} PLATES FOR FIELD STARS LACKING VELOCITIES

STAR HD	TYPE	PLATE	n	v_r (km/sec)
701	wk metal	E2124	9	73
2796	wk metal	E2124	8	-27
4084	Ba II	E2124	16	- 1
5424	Ba II	E2124	13	-21
198718	wk G	E2122	14	- 9
201557	wk G	E2123	11	- 4
204046	wk G	E2123	7	8:
207774	wk G	E2123	15	- 3
210709	Ba II	E2123	16	10
211173	Ba II	E2123	14	-45
211594	Ba II	E2123	13	-24
211988	weak metal	E2124	8	-48

within narrow regions of the CMD, a brief description of the present material illuminates several aspects of the M22–ω Cen comparison. Figure 2, which is a montage of intensity tracings made with the COSMOS microphotometer at the Dominion Astrophysical Observatory, serves as the basis of the ensuing discussion. The uppermost tracing is of star II-75 in M15, while the others are M22 stars displayed in order of decreasing luminosity according to Figure 1. To facilitate intercomparison with the CMD, each M22 spectrum is labeled with the same letter used to plot the star in Figure 1. An approximate wavelength scale is given at the bottom of the figure. Several dominantly atomic features are identified on the bottom left, while on the bottom right some prominent molecular features are marked. (Even though the labels on the

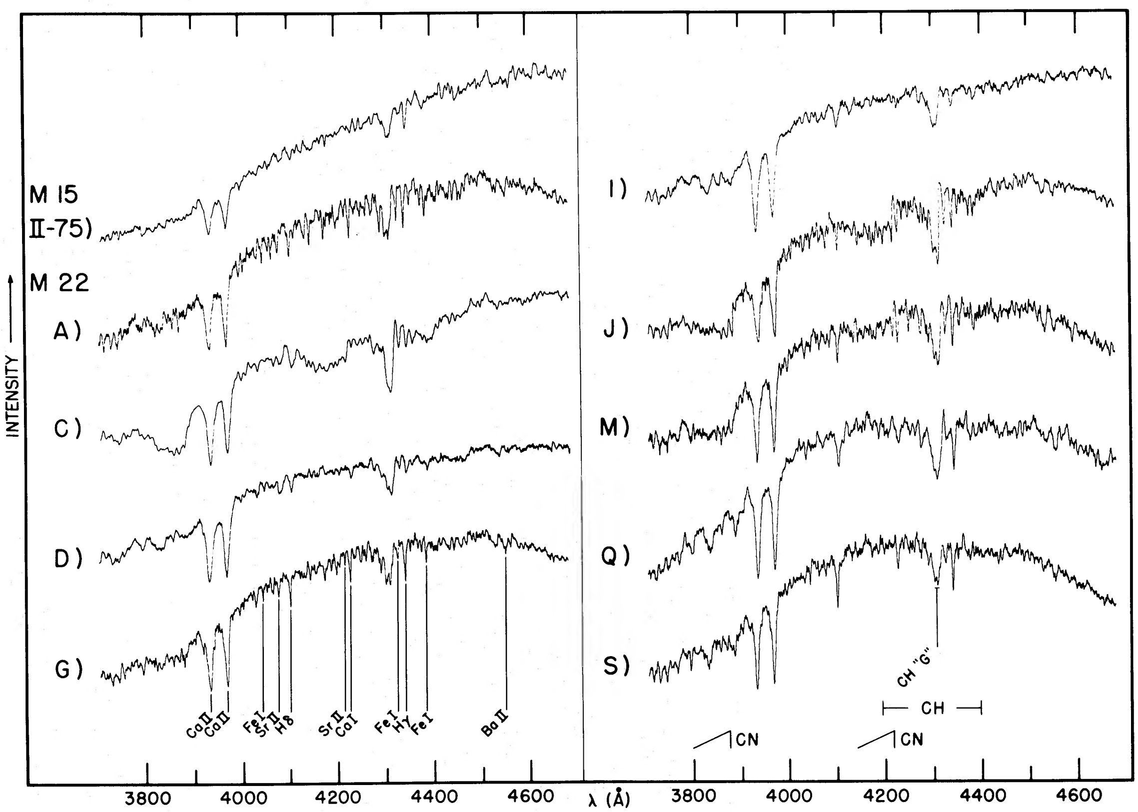

FIG. 2.—Intensity tracings for a star in M15 and for a selection of M22 stars; see the text for a description of this figure.

plots refer to single species, the reader is cautioned that, at the resolution of these spectra, most of the features are blends.)

Without doubt the most striking conclusion to be drawn from Figure 2 is the existence of a second star, IV-24 (= J), that is virtually identical in appearance to the HHM77 mild CH star, III-106 (= C). As mentioned in § I, McClure and Norris (1977) found the latter star to exhibit features virtually identical to those of HD26, a classical CH star (cf. Wallerstein and Greenstein 1964); by analogy, IV-24 may be considered to be a mild CH star. Particularly noticeable are the very strong CN and G (CH) bands in both stars. The subgiant III-32 also exhibits noticeably enhanced CN and G bands, and may be a mild CH star similar to the field stars discussed by Yamashita (1972, 1975) and Bond (1974). Of course, it may also be only a star with enhanced CN and CH features, and higher resolution spectra, particularly including the C_2 bandhead region, should be obtained.

Our spectra extend Lloyd Evans's (1978) and Mallia's (1978) findings concerning the G-band strengths of M22 giants, namely that all cluster giants show prominent G bands, which in many cases, seem comparable in strength to those of Population I stars, even though the cluster metallicity is quite low ([Fe/H] ~ -1.9). Furthermore, we concur with Lloyd Evans's (1978) comment that the blends containing Ba II 4554 Å or Sr II 4077 Å appear with about equal strength in all M22 stars, including the mild CH stars, III-106 and IV-24, and the possible subgiant CH star, 6811. To date, no M22 giant has been found to exhibit the weak G band phenomenon common to stars with metal-poor globular clusters (cf. Norris and Zinn 1977).

V. DISCUSSION

The combined studies of HHM76, 77, Mallia (1976, 1978), and Lloyd Evans (1978) suggest that a significant range of CN strengths exists in the metal-poor globular cluster M22. The present study has provided confirming evidence, particularly with the identification of a second mild CH star on the M22 giant branch and a possible one on its subgiant branch. Whether the range of CN and CH strengths is actually a dichotomy rather than a continuum is not yet completely clear, although the DDO photometry of HHM77, Lloyd Evans's (1978) and Mallia's (1978) description of their spectra, and the spectra of Figure 2 suggest there is a continuum of CN strengths. Our observations also suggest that variations in at least CN strengths persist to absolute magnitudes fainter than the level of the junction of the horizontal and giant branches, i.e., to absolute magnitudes where presumably only stars ascending the giant branch for the first time are being observed. Analogous behavior is observed for features in stars in the very metal deficient cluster, M92 (Kraft 1978), as well as the metal-rich cluster, 47 Tuc (HHM76, 77; Hesser 1978; Norris and Freeman 1979). All M22 stars known to possess strongly enhanced CN and CH, including III-78 (Lloyd Evans 1978), appear to lie on the red side of the giant and subgiant branches (cf. the preliminary CMD in Figure 1)[2]. The range of band strengths to be expected from temperature *alone* is exceeded by stars III-106, IV-24, and III-78, and probably by III-32 as well. (But photoelectric photometry of the certified members should be obtained before reaching definitive conclusions regarding possible temperature effects.) Examination of our spectra suggests that other metallicity indicators, particularly lines of Ca I and II, may also be different from star to star, but these suspicions must await acquisition of repeat observations and subsequent detailed analysis.

The observed range of CN strengths implies a substantial enhancement of [N/H] in at least some M22 stars (cf. Mallia 1978; Deming 1978), an enhancement that seems all the more remarkable when the low overall metallicity of the cluster is taken into account. Until now wide ranges of CN strengths have been recognized only in globular clusters at least as metal-rich as M5 (HHM76, 77; cf. also Osborn 1971, 1973; McClure and Osborn 1974; McClure and Norris 1974; Bell, Dickens, and Gustaffson 1975; Hesser 1978; Norris 1978) or the peculiar cluster, ω Cen. The existence of intracluster CN strength variations in M22 might be more reconcilable with our knowledge of such variations in other clusters if it could be demonstrated that Manduca and Bell's (1968) [Ca/H] ratio, -1.25, for M22 RR Lyrae stars represents $[Fe/H]_{M22}$. However, such a high metallicity is at odds with all other estimates. Thus, while Lloyd Evans (1978) tentatively concluded that M22 stars "... show at most mild forms of the peculiarities found in ω Cen ...," our observations seem consistent with HHM76, 77's suggestion that although M22 is not as extreme as ω Cen its stars seem to differ significantly from those of other metal-poor clusters.

One or two points that bear upon this fascinating question and that were not mentioned in §§ I or IV should be noted. First, in the I, $V - I$ diagrams of ω Cen, M22, and 47 Tuc (Lloyd Evans 1974, 1975, 1977), as well as in the usual V, $B - V$ diagrams (Woolley *et al.* 1966; Cannon and Stobie 1973; Lloyd Evans 1977; Hesser and Hartwick 1977; Lee 1977), M22 shows a width intermediate between that of 47 Tuc and ω Cen, but closer to that of 47 Tuc. Clearly, as Lloyd Evans's work has shown, the full value of such comparisons for illuminating intrinsic differences between these clusters can only be realized when the CMDs are cleansed of field stars. A proper-motion study of M22 would be invaluable in this regard. But as noted by HHM77, inspection of the available M22 CMDs, as well as that of adjacent fields (Arp 1959), suggests that in spite of its galactic coordinates those diagrams seem to be remarkably free—at least for the brighter regions—from contaminating foreground

[2] Star III-78 was not measured by Hartwick and Hesser (1979) but can be located in Figure 1 by using the photometry of other observers. According to Lloyd Evans (1975) it has $V = 12.98$, $B - V = 1.32$, while Alcaino (1977) assigns it $V = 12.90$, $B - V = 1.36$, so that in Figure 1 it would presumably lie slightly above star K in D and slightly blueward (left) of star J in O-D.

stars, a conclusion borne out by the spectroscopic work of Lloyd Evans (1978), Mallia (1978), and this paper. At the same time, even elimination of known foreground stars from the DDO diagrams does not make them resemble those for comparably metal-poor globular clusters, a result that may only reflect increased photometric errors arising in the difficult M22 field and/or the continued inclusion of unrecognized field stars. But we consider equally tenable that it may be indicative of CN and metallicity properties that distinguish M22 stars from stars in other metal-poor clusters. Identification of the principal sequences in the M22 CMD arrays has not proved to be entirely without uncertainty either. Arp and Melbourne (1959), Lloyd Evans (1975, 1978), and Alcaino (1977) have found M22 to possess an abnormally weak asymptotic giant branch (AGB), while in Eggen's (1977) diagrams it appears clearly delineated. Although essentially complete for the inner regions, Figure 1 does not show clearly separated AGB and giant branches, a result that may reflect a merging of the two due to somewhat enhanced intrinsic widths, as is the case for ω Cen. Finally, the lack of a discernible weak G-band effect *might* be evidence that the M22 AGB is different from those of other metal-poor globular clusters.

Whether or not the range of CN strengths among evolved M22 stars is due to mixing of CNO processed elements to the surface, to primordial inhomogeneities, or to heretofore unexpected effects [such as the presence of interactive binaries (McClure, private communication)] is not yet clear. Spectroscopic observations yielding radial velocities and line-strength parameters, improved CMDs, proper motion studies, and extensive intermediate and broad-band (particularly CO) photometry of radial-velocity members are all capable of elucidating the extent of M22's apparent peculiarities and should be vigorously pursued.

We wish to thank the CTIO Telescope Allocation Committee and Director for their generous support of this program; the CTIO staff for their hospitality and, particularly, A. Gomez, O. Saa, and R. Venegas for their help with the equipment; F. D. A. Hartwick for generous assistance with Figure 1; and our DAO colleagues W. Fisher, J. B. Hutchings, D. Crampton, J. M. Nemec, D. Duncan, H. Draper, and R. Haapala for their much appreciated contributions to this work. This research was supported in part by a grant to G. L. H. H. by the National Research Council of Canada.

REFERENCES

Alcaino, G. 1977, *Astr. Ap. Suppl.*, **29**, 383.
Arp, H. C. 1959, *A.J.*, **64**, 33.
Arp, H. C., and Melbourne, W. G. 1959, *A.J.*, **64**, 28.
Batten, A. H. 1978, *Vistas in Astronomy*, **22**, 265.
Batten, A. H., Crampton, D., Fletcher, J. M., and Morbey, C. L. 1971, *Pub. Dom. Ap. Obs.*, **13**, 441.
Bell, R. A., Dickens, R. J., and Gustaffson, B. 1975, *Bull. AAS*, **7**, 535.
Bond, H. E. 1974, *Ap. J.*, **194**, 95.
———. 1975, *Ap. J.* (*Letters*), **202**, L47.
———. 1978, paper presented at NATO Globular Cluster Conference, Cambridge.
Butler, D. 1975, *Ap. J.*, **200**, 68.
Butler, D., Dickens, R. J., and Epps, E. 1978, *Ap. J.*, **225**, 148.
Cannon, R. D., and Stobie, R. S. 1973, *M.N.R.A.S.*, **162**, 207.
Canterna, R. 1975, *Ap. J.* (*Letters*), **200**, L63.
Crampton, D., Hutchings, J. B., and Cowley, A. P. 1978, *Ap. J.* (*Letters*), **225**, L63.
Deming, D. 1978, *Ap. J.*, **222**, 246.
Dickens, R. J. 1972, *M.N.R.A.S.*, **159**, 7P.
Eggen, O. J. 1977, *Ap. J.*, **213**, 767.
Freeman, K. C. 1978, paper presented at NATO Globular Cluster Conference, Cambridge.
Freeman, K. C., and Rodgers, A. W. 1975, *Ap. J.* (*Letters*), **201**, L71.
Harding, G. A. 1962, *Observatory*, **82**, 205.
———. 1965, *R.O.B.*, No. 99.
Hartwick, F. D. A. 1968, *Ap. J.*, **154**, 475.
Hartwick, F. D. A., and Hesser, J. E. 1979, in preparation.
Hesser, J. E. 1976, *Pub. A.S.P.*, **88**, 849.
———. 1978, *Ap. J.* (*Letters*), **223**, L117.
Hesser, J. E., and Hartwick, F. D. A. 1977, *Ap. J. Suppl.*, **33**, 488.
Hesser, J. E., Hartwick, F. D. A., and McClure, R. D. 1976, *Ap. J.* (*Letters*), **207**, L113 (HHM76).
———. 1977, *Ap. J. Suppl.*, **33**, 471 (HHM77).
Hesser, J. E., and Shawl, S. J. 1978, paper presented at the NATO Globular Cluster Conference, Cambridge.
Hutchings, J. B., Crampton, D., Cowley, A. P., and Osmer, P. S. 1977, *Ap. J.*, **217**, 186.
Joy, A. H. 1949, *Ap. J.*, **110**, 105.
Kinman, T. D. 1959, *M.N.R.A.S.*, **119**, 157.
Kraft, R. P. 1978, paper presented at the NATO Globular Cluster Conference, Cambridge.
Lee, S.-W. 1977, *Astr. Ap.*, **27**, 38.
Lindsay, E. M. 1956, *Vistas in Astronomy*, **2**, 1057.
Lloyd Evans, T. 1974, *M.N.R.A.S.*, **167**, 393.
———. 1975, *M.N.R.A.S.*, **171**, 647.
———. 1977, *M.N.R.A.S.*, **181**, 591.
———. 1978, *M.N.R.A.S.*, **182**, 293.
Mallia, E. A. 1976, *M.N.R.A.S.*, **177**, 73.
———. 1978, *Astr. Ap.*, **70**, 115.
Manduca, A., and Bell, R. A. 1978, *Ap. J.*, **225**, 908.
Mayall, N. U. 1946, *Ap. J.*, **104**, 290.
McClure, R. D. 1978, *Mem. Soc. Ast. Italiano*, in press.
McClure, R. D., and Norris, J. 1974, *Ap. J.*, **193**, 139.
———. 1977, *Ap. J.* (*Letters*), **217**, L101.
McClure, R. D., and Osborn, W. 1974, *Ap. J.*, **189**, 405.
Nemec, J. 1978, M.Sc. thesis, University of Victoria.
Norris, J. 1978, in *IAU Symposium No. 80, The HR Diagram*, ed. A. G. Davis Philip and D. S. Hayes (Dordrecht: Reidel), p. 195.
Norris, J., and Bessell, M. S. 1975, *Ap. J.* (*Letters*), **201**, L75.
———. 1977, *Ap. J.* (*Letters*), **211**, L91.
Norris, J., and Freeman, K. C. 1979, *Ap. J.* (*Letters*), **230**, L179.
Norris, J., and Zinn, R. 1977, *Ap. J.*, **215**, 74.
Osborn, W. 1971, Ph.D. thesis, Yale University.
———. 1973, *Ap. J.*, **186**, 725.
Petrie, R. M. 1962, in *Stars and Stellar Systems, Astronomical Techniques*, ed. W. A. Hiltner, **2** (Chicago: University of Chicago Press), p. 63.
Smith, M. G., Hesser, J. E., and Shawl, S. J. 1976, *Ap. J.*, **206**, 66.
Wallerstein, G., and Greenstein, J. L. 1964, *Ap. J.*, **139**, 1163.
Wing, R. F., and Stock, J. 1973, *Ap. J.*, **186**, 979.
Woolley, R. v. D. R., *et al.* 1966, *Roy. Obs. Ann.*, No. 2.
Yamashita, Y. 1972, *Ann. Tokyo Astr. Obs.*, **13**, 169.
———. 1975, *Pub. Ast. Soc. Japan*, **27**, 325.

G. L. H. Harris: Department of Physics, University of Waterloo, Waterloo, ON, N2L 3G1, Canada

J. E. Hesser: Dominion Astrophysical Observatory, 5071 W. Saanich Road, Victoria, BC, V8X 3X3, Canada