ON THE INTRINSIC COLORS OF RR LYRAE STARS IN M3

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ABSTRACT

The available three-color data for selected RR Lyrae variables in M3 are summarized in Table 1. These data were taken from two recent photometric studies and are reduced to the U, B, V system. It is pointed out that the color excess of field RR Lyrae stars probably cannot be obtained from a measured $B - V$ index and the period alone because the period-color relation is not expected to be unique. If there is a spread, ΔM_V, in the absolute magnitude of RR Lyrae stars, then different period–intrinsic color relations will obtain (Sandage 1958*a*, Fig. 3). It is therefore important that both $U - B$ and $B - V$ be observed, to determine E_{B-V} and E_{U-B} for RR Lyrae variables.

The intrinsic colors of RR Lyrae stars are of some importance in (1) testing the similarity of RR Lyrae stars in globular clusters and in the general field and (2) in estimating absorption and reddening effects in such regions as the galactic center, where RR Lyrae stars are found. Two recent studies provide three-color data for selected RR Lyrae stars in the globular cluster M3. Roberts and Sandage (1955) obtained light-curves in two colors for 49 variables in M3. These data are on an m_{pg}, m_{pv} photometric system defined by 64 stars in Table II of the original paper on M3 (Sandage 1953). The m_{pg} and m_{pv} values can be transformed to the B, V system by $B - m_{pg} = +0.17$ and $V - m_{pv} = -0.02$ valid in the range of $0.30 > m_{pg}\text{–}m_{pv} > -0.10$. These equations were obtained from comparison of the m_{pg} and m_{pv} values for the 64 stars already mentioned with the B, V values for most of the same stars determined by Johnson and Sandage (1956, Table 3). The large correction to m_{pg} is due primarily to the change in zero-point definition of the B system from the international photographic system.

Light-curves on the U system have been determined for 37 selected variables in M3 by R. H. and H. V. Baker (1956). The U values for the 46 standards used by the Bakers in their photometry were determined as a subprogram for the U, B, V photometry of M3 already cited.

Table 1 of the present paper is a summary of all available photometric data on the U, B, V system for 49 variables in M3. The median magnitude is defined in the usual way as $\frac{1}{2}[m(\max) + m(\min)]$. The mean magnitude was found by converting the light-curves into intensity units, planimetering the curves for mean intensity, and converting the mean intensity back into magnitude units. Most of the columns of Table 1 are self-explanatory. The last four columns give, respectively, the amplitudes of the light-variation in U, B, and V and the distance of each variable from the cluster center. The data in Table 1 are sufficient to recover the magnitudes at maximum and minimum light in U, B, and V.

Table 1 is similar to Table III published by the Bakers. However, for a reason unexplained at present, the $U - B$ and $B - V$ data of the Bakers' tabulation are in error by about -0.04 mag. in $U - B$ and $+0.08$ mag. in $B - V$. This appears to be a numerical error in the conversion of m_{pg} to B and m_{pv} to V. It probably came about from an error in the conversion tables given to the Bakers by the present author. The values in Table 1 of the present paper are believed to be correct.

Figure 1 is the $U - B$, $B - V$ diagram for stars of Table 1, together with non-variable horizontal-branch stars bordering the variable-star domain taken from Table 3 of John-

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TABLE 1. SUMMARY DATA FOR M 3 VARIABLE STARS ON THE UBV SYSTEM

No.	Period	Bailey Type	U Med	U Mean	B Med	B Mean	V Med	V Mean	U-B Mean	B-V Mean	A_U	A_B	A_V	r"
1	0.5206324	a, b	15.68	15.86	15.61	15.80	15.34	15.51	+0.06	0.29	1.10	1.33	0.97	129
6	.5143207	a, b	15.72	15.95	15.77	15.94	15.48	15.62	+0.01	0.32	1.22	1.21	0.93	138
9	.5415672	a, b	15.88	16.00	15.75	15.97	15.56	15.68	+0.03	0.29	1.14	1.42	1.03	358
12	.3178890	c	15.87	15.86	15.78	15.74	15.55	15.53	+0.12	0.21	0.44	0.62	0.50	146
16	.5115072	a, b	15.92	16.04	15.85	16.00	15.56	15.71	+0.04	0.29	1.15	1.46	1.11	316
18	.5163462	a, b	15.94	16.10	15.82	16.02	15.58	15.70	+0.08	0.32	1.32	1.30	0.91	311
19	.631981	a, b	16.00	16.07	16.07	16.11	15.64	15.69	-0.04	0.42	0.55	0.47	0.41	428
21	.5157298	a, b	15.80	15.99	15.82	15.53	15.69	15.69	-0.01	0.31	1.33	1.28	1.00	347
24	.6633499	a, b	15.85	15.90	15.79	15.86	15.43	15.47	+0.04	0.39	0.60	0.85	0.70	148
25	.480048	a, b	-	-	15.64	15.84	15.39	15.57	-	0.27	-	1.42	1.14	128
26	.5977479	a, b	15.71:	15.90:	15.73	15.86	15.42	15.56	+0.04:	0.30	0.98:	1.35	1.04	182
27	.5790981	a, b	15.88	15.95	15.78	15.96	15.48	15.59	-0.01	0.37	0.99	0.94	0.71	151
34	.5591078	a, b	15.93	15.99	15.91	16.00	15.55	15.65	-0.01	0.35	0.58	0.59	0.51	218
36	.5455861	a, b	15.86	15.98	15.75	15.87	15.53	15.59	+0.11	0.28	1.23	1.33	1.05	176
37	.3266402	c	15.90	15.93	15.91	15.90	15.68	15.65	+0.03	0.25	0.57	0.61	0.48	288
40	.5515419	a, b	15.94:	16.06:	15.88	16.01	15.62	15.69	+0.05:	0.32	0.83:	1.27	0.88	294
46	.613367	a, b	-	-	15.90	15.98	15.52	15.58	-	0.40	-	0.68	0.53	138
48	.6278087	a, b	15.78	15.84	15.80	15.87	15.45	15.48	-0.03	0.39	0.62	0.66	0.54	163
51	.5839856	a, b	15.95	16.05	15.83	15.98	15.58	15.65	+0.07	0.33	0.96	1.18	0.88	228
55	.5298114	a, b	-	-	15.78	15.97	15.54	15.67	-	0.30	-	1.42	1.08	383
56	.329596	c	15.92	15.92	15.89	15.87	15.62	15.63	+0.05	0.24	0.51	0.65	0.50	385
60	.7077216	a, b	-	-	15.87	15.93	15.64	15.55	-	0.38	-	-.73	0.57	434
64	.6054592	a, b	16.00	16.05	15.93	16.02	15.64	15.67	+0.03	0.35	0.80	0.95	0.77	350
65	.6683397	a, b	15.89	15.87	15.75	15.85	15.47	15.51	+0.02	0.34	1.02	1.16	0.95	351
71	.5490517	a, b	15.85	15.99	15.73	15.93	15.46	15.62	+0.06	0.31	0.82	1.11	0.91	161
72	.4560721	a, b	15.80	16.00	15.76	15.94	15.44	15.68	+0.06	0.26	1.61	1.63	1.36	446
74	.4921415	a, b	-	-	15.71	15.89	15.51	15.63	-	0.26	-	1.47	1.20	175
75	.3140813	c	15.92	15.90	15.85	15.85	15.62	15.61	+0.05	0.24	0.59	0.59	0.49	167
81	.5291108	a, b	15.82	16.00	15.72	15.95	-	-	+0.05	-	1.15	1.41	-	491
83	.5012423	a, b	-	-	15.79	15.98	15.47	15.67	-	0.31	-	1.42	0.09	456
84	.5957289	a, b	15.91	15.98	15.89	15.99	15.56	15.60	-0.01	0.39	0.72	0.94	0.66	177
85	.355820	c	15.83	15.79	15.73	15.70	15.53	15.51	+0.09	0.19	0.52	0.64	0.46	380
90	.5170344	a, b	-	-	15.82	15.97	15.48	15.64	-	0.33	-	1.38	1.12	212
93	.6023041	a, b	-	-	15.93	16.03	15.58	15.65	-	0.38	-	0.97	0.69	509
94	.5236921	a, b	-	-	15.81	15.95	15.53	15.69	-	0.26	-	1.39	0.94	538
96	.4994538	a, b	-	-	15.65	15.82	15.39	15.55	-	0.27	-	1.49	1.07	286
105	.2877445	c	15.83	15.83	15.72	15.73	15.53	15.54	+0.10	0.19	0.36	0.39	0.28	193
107	.3090344	c	15.96	15.95	15.88	15.87	15.65	15.65	+0.08	0.22	0.53	0.64	0.54	344
108	.5196047	a, b	15.88	16.02	15.84	15.99	15.54	15.70	+0.03	0.29	1.05	1.36	1.03	380
118	.4993795	a, b	-	-	15.72	15.92	-	-	-	-	-	1.56	-	326
119	.5177510	a, b	15.76	15.96	15.72	15.89	15.54	15.63	+0.07	0.26	1.41	1.48	1.20	275
120	.6401377	a, b	15.99	16.03	16.02	16.06	15.63	15.66	-0.03	0.40	0.52	0.56	0.42	376
124	.752438	a, b	-	-	15.94	15.94	15.54	15.54	-	0.40	-	0.42	0.39	212
125	.3498210	c	15.93	15.92	15.95	15.91	15.66	15.65	+0.01	0.26	0.46	0.53	0.37	229
126	.3484044	c	15.90	15.93	15.87	15.87	15.62	15.60	+0.06	0.27	0.47	0.52	0.39	147
140	.3331259	c	-	-	15.65	15.64	15.38	15.40	-	0.24	-	0.53	0.39	110
C	.28718	c	15.88	15.88	15.78	15.79	15.60	15.59	+0.09	0.20	0.19	0.16	0.15	318
I-42	.9163	?	15.98	15.98	16.00	16.00	15.58	15.58	-0.02	0.42	0.22	0.14	0.12	357
I-100	.9987:	?	-	-	15.96:	15.96:	15.55:	15.55:	-	0.41	-	0.15:	0.15:	195

son and Sandage (1956). The intrinsic line for main-sequence stars is given as a dashed line and is taken from Johnson and Morgan (1953). There is no reason to expect the RR Lyrae intrinsic line to agree with the main-sequence line, because differences in the electron pressure, due principally to the low surface gravity of the RR Lyrae stars, will cause a difference in the energy distribution of the two types of stars, especially in the region of the Balmer jump. This will produce differences in the $U - B$ and $B - V$ values. The ultraviolet deficiency of $\Delta(B - V) = +0.04$ mag. for the bluest stars of Figure 1 is believed to be due to this surface-gravity effect.

Presumably, the intrinsic line for RR Lyrae stars in Figure 1 permits us to find the E_{B-V} and E_{U-B} for field RR Lyrae stars relative to the M3 variables. We cannot, of course, be certain that M3 is unreddened. If the optical half-thickness of the Galaxy is 0.25 mag. in B, then E_{B-V} for M3 would be 0.06 mag. However, the cosecant law is known to be only a statistical relation which may be incorrect in any individual case.

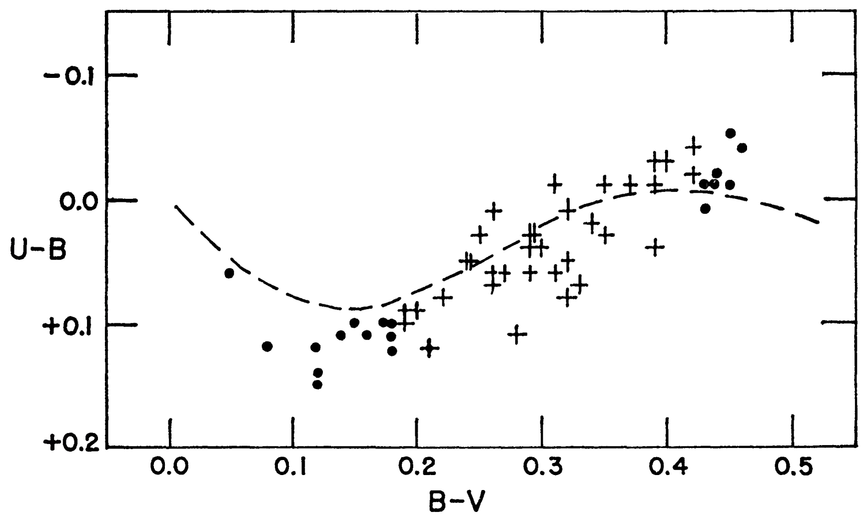

FIG. 1.—Two-color index plot for the variables of Table 1. Non-variable stars bordering the domain of instability are shown as circles. Variable stars are shown as crosses. The main-sequence line is drawn for comparison. There is no reason to expect the variables to fall on the main-sequence line.

The bluest of the horizontal-branch stars in M3 is III-87 with $V = 17.60$, $B - V = -0.38$, and $U - B = 1.04$. These values should be compared with the bluest field star known, BD$+28°4211$, with $B - V = -0.34$, $U - B = -1.26$. The comparison shows that M3 cannot be reddened very much, if at all. In what follows, we assume that M3 is unreddend and that the colors given in Table 1 are intrinsic.

The period-amplitude, period-color, and amplitude-color relations for the M3 variables can be plotted from Table 1. These are similar to plots given by Roberts and Sandage (1955). At one time it was believed that the color excess of any field RR Lyrae star, relative to the M3 variables, could be found if only the period and the $B - V$ were known. The method would have been to read the $\Delta(B - V)$ from the period-color plot. However, if the explanation of the mean period differences between various globular clusters is correct (Sandage 1958*a*, Fig. 3), we now expect that RR Lyrae stars of different M_V will satisfy *different* period-intrinsic color relations. And this will vitiate the possibility of finding the color excess without a $U - B$ color. Indeed, measured differences of $B - V$ from, say, the M3 period-color plot for any unreddened RR Lyrae field star is expected to determine the absolute magnitude difference between this star and the M3 variables by an equation of the form $\log P = f(M_v, B - V, Q)$, which results from $P\sqrt{\rho} = Q$ (Sandage 1958*a*, *b*). The procedure to find ΔM_V is straightforward but is as yet unproved. What is needed is a set of three-color data, similar to Table 1, in a globular cluster such as ω Cen or M15, where the mean period of the RR Lyrae ab variables is $\bar{P} \approx 0.65$ day instead of $\bar{P} \approx 0.55$ day, as in M3. This would correspond to the cluster *A* of Figure 3 of Sandage (1958*a*), while M3 would correspond to cluster *B*. The prediction is that the $U - B$, $B - V$ plot for M15 variables would be like Figure 1 of this paper, while the period-color and period-amplitude relations will be shifted in M15 by $\Delta \log P = \log 0.65 - \log 0.55 = 0.07$ relative to M3. If such is the case, then we can find the ΔM_V for any field RR Lyrae star relative to M3 by first fitting the three-color data for the field star to the $U - B$, $B - V$ diagram to obtain E_{B-V}. The shift of the resulting normal color, $(B - V)_0$, in the period-color plot for M3 will then determine $\Delta M_V \equiv M_V(\text{star}) - M_V(\text{M3})$ from the $\log P = f(M_V, B - V, Q)$ relation. The necessary three-color observations in M15 are now under way by Mary L. Connelley, to test the requirements of the method.

The only purpose of the last paragraph of this note is to point out that there are strong reasons for believing that the color excess for field RR Lyrae stars *cannot* be found from two-color observations alone because there may be a non-unique period-color relation. It is therefore suggested that all photometric observations of field RR Lyrae stars should be made on a three-color system if the color excess is required.

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