THE HELIUM ABUNDANCE IN THE ENVELOPES OF THE BLUEST RR LYRAE STARS IN GLOBULAR CLUSTERS AND DEPENDENCE OF GLOBULAR CLUSTER VARIABLE STAR PROPERTIES ON CHEMICAL COMPOSITION

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Abstract. The helium abundance Y in the envelopes of RR Lyrae stars in globular clusters has been estimated. The values of Y range from 0.07 to 0.59. The properties of variable stars in globular clusters of two types distinguished by a type of dependence of the horizontal branch form on the chemical composition are compared. The clusters of type I are shown to be on the average poorer in RR Lyrae stars than those of type II. The RR Lyrae stars in type I clusters are on the average brighter by 0.1 mag. It is found that as Y increases, the cluster richness in W Virginis variables decreases.

It has long been known that a number of properties of globular cluster variable stars depend on chemical abundance.

In the present report we shall discuss some of these properties in connection with our discovery of the separation of globular clusters into two groups distinguished by a type of dependence of the horizontal branch form on chemical abundance.

Recently Kukarkin has developed a system of metallicity indexes (IM) based on many determinations by other authors (Kukarkin and Russev, 1972) of metal abundance in the atmospheres of globular cluster stars. Apparently the metallicity indexes most fully and objectively reflect our modern knowledge of metal abundance in globular cluster stars.

Sandage (1969), guided by Christy's (1966) theoretical calculations, suggested a method of determination of helium abundance from the $(B-V)$ colour of the blue edge of the RR Lyrae strip on the Hertzsprung-Russell diagram. Sandage (1969, 1970) applied his method for obtaining the helium abundance in horizontal branch stars of the globular clusters M3, M13, M15, and M92. But at the present time the diagrams for 41 globular clusters have been published. For 27 of them the colour of the blue edge of the RR Lyrae strip is determined with sufficient confidence. We have somewhat altered Sandage's method, having applied Newell's (1970) colour-effective temperature relation for blue horizontal branch stars and having taken into account the results of new calculations of pulsation models made by Iben and Huchra (1970). Using this altered method, we have determined the helium abundance Y in the envelopes of the bluest RR Lyrae stars in 27 globular clusters (Mironov, 1971, 1972). The values of Y obtained range from 0.07 to 0.59.

The comparison of the quantities IM and Y and their product $IM \cdot Y$ with the parameters of the horizontal branch form shows that all globular clusters can be divided into two groups. To quantitatively describe the horizontal branch form we consider

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two new parameters. The first of them is the number of blue stars (i.e. stars to the left of the RR Lyrae strip expressed as a fraction of the total number of non-variable horizontal branch stars. The second parameter is the difference in $(B-V)$ between the red end of the horizontal branch and that point on the horizontal branch at which the greatest concentration of stars occur. The former point is designated as $(B-V)_2$, the latter one as $(B-V)_1$.

The resulting separation of globular clusters into two groups according to the type of dependence of the horizontal branch form on the abundance is illustrated by Figures 1 and 2, where the type I clusters are indicated by crosses and the type II clusters by filled circles.

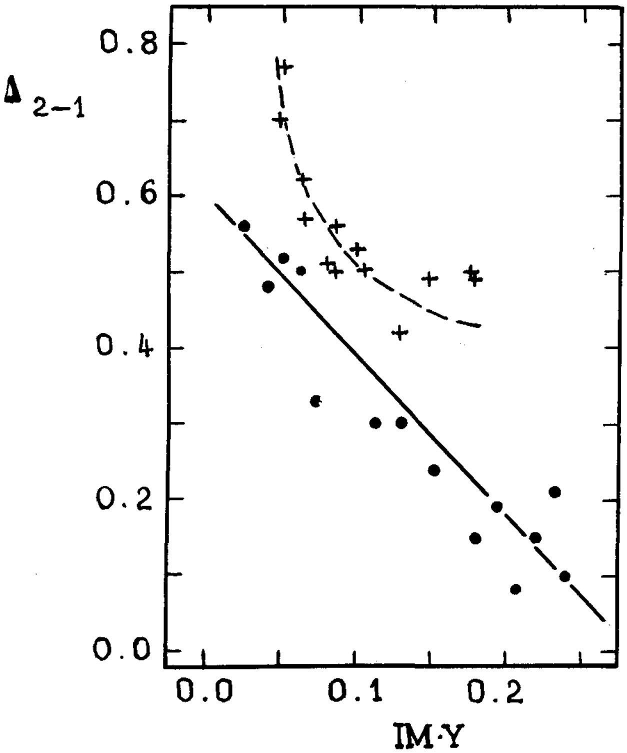

Fig. 1. The dependence of the colour difference between the red end of the horizontal branch and the point of maximum star concentration in the HB as a function of chemical abundance. Crosses indicate type I cluster, circles type II clusters.

The other properties of the variable stars in these two classes of clusters also differ, which can be seen from Table I, where they are listed with the abundance parameters.

The first column of this table contains the designation of clusters. The abundance parameters IM, Y and $IM \cdot Y$ are given in the next three columns. The type I clusters have a rather small range of metallicity indexes, and their metal abundance is on the average lower than that of the type II clusters.

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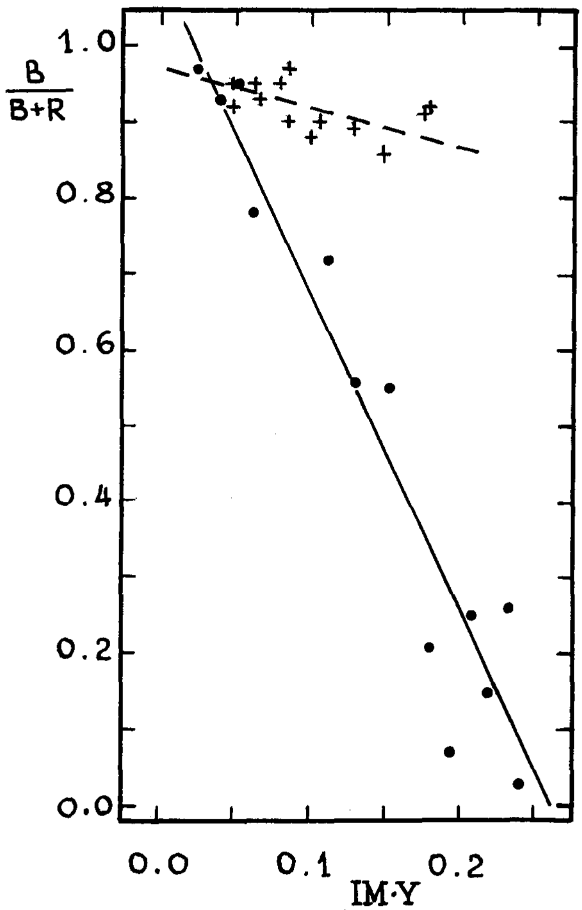

Fig. 2. The number of HB stars bluer than RR Lyr stars (expressed as a fraction of all non-variable HB stars) vs chemical abundance. Symbols as in Figure 1.

The number N_{RR} of RR Lyrae stars in the clusters under consideration are given in the fifth column, and the sixth column contains the same numbers corrected for the richness of a cluster N'_{RR}. Such corrections are quite necessary when comparing the number of variables in various clusters, as all other things being equal, the probability of finding a star of some type is proportional to the total number of stars in a cluster, i.e. to cluster richness. We made this correction by using a factor that is inversely proportional to the absolute cluster luminosity, the richness of the absolutely brightest cluster, ω Cen, being unity. It is obvious that type I clusters are essentially poorer in RR Lyrae stars than the type II clusters. As Figure 3 shows, the relative quantity of RR Lyrae variables in both types of clusters increases at first, and then begins decreasing, the type I cluster curve always staying lower than the type II cluster curve. This dependence can be easily explained if we take into account that with the increasing of $IM \cdot Y$ the $(B-V)_1$ point moves from the blue area into the red one. The

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TABLE I

Properties of globular clusters

Clusters NGC name (1)		IM (2)	Y (3)	$IM \cdot Y$ (4)	N_{RR} (5)	N'_{RR} (6)	P_{tr} (7)	M_{RR}^{bol} (8)	N_{cw} (9)	N'_{cw} (10)
Type I Clusters										
4147		0.35	0.42	0.147	9	320.8	0.504	+0.78	?	–
5024	M53	0.30	0.59	0.177:	42	210.4	0.529	+0.69	1	5.01
5139	ω Cen	0.33	0.26	0.086	142	142.0	0.518	+0.73	7	7.00
5466		0.27	0.47:	0.127:	18	525.2	0.542	+0.65	?	–
5897		0.31	0.21	0.065	6	87.5	–	–	?	–
6205	M13	0.36	0.24	0.086	3	16.6	–	–	3	16.65
6218	M12	0.38	0.26	0.099	0	0	–	–	1	12.94
6254	M10	0.36	0.13	0.047	0	0	–	–	2	23.40
6397		0.33	0.15:	0.050:	0	0	–	–	?	–
6752		0.33	0.53	0.175	0	0	–	–	?	–
7089	M2	0.31	0.26	0.081	17	53.7	0.520	+0.72	4	12.66
7492		0.31	0.34	0.105	0	0	–	–	?	–
mean		0.33	0.32	0.104	20	113.0	0.520	+0.71	3	12.94
Type II Clusters										
104	47 Tuc	0.57	0.42	0.239	2	4.7	–	–	?	–
362		0.43	–	–	7	36.7	0.474	+0.89	?	–
4833		0.34	0.07	0.024	6	29.3	–	–	?	–
5053		0.26	0.28	0.073	10	506.2	0.576	+0.54	?	–
5272	M3	0.37	0.35	0.130	201	910.5	0.490	+0.83	1	4.53
5904	M5	0.36	0.31	0.112	99	514.8	0.500	+0.80	2	10.40
6121	M4	0.49	0.31	0.152	41	880.7	0.433	+1.06	?	–
6171		0.50	0.39	0.195	22	522.9	0.438	+1.03	?	–
6341	M92	0.23	0.22	0.051	15	109.6	0.560	+0.59	?	–
6362		0.43	0.59:	0.254:	15	310.5	0.460	+0.94	?	–
6656	M22	0.31	0.13	0.040	19	129.0	0.547	+0.63	3	20.37
6712		0.50	0.44	0.220	10	185.4	0.481	+0.87	?	–
6723		0.53	0.44	0.233	19	419.5	0.444	+1.01	?	–
7006		0.39	0.53:	0.207:	74	818.4	0.490	+0.83	?	–
7078	M15	0.24	0.26	0.062	93	356.9	0.575	+0.54	2	7.46
mean		0.40	0.33	0.135	42	381.7	0.498	+0.81	2	10.69

maximum number of RR Lyrae stars naturally occurs when this point is situated in the middle of the instability strip, the colour of which varies comparatively little among clusters.

The seventh column lists the values of a critical transition period P_{tr} from the pulsations of the *ab* type to the *c* type. According to Christy's (1966) investigation this value is related to the luminosity of the RR Lyrae stars by the equation

$$M_{RR}^{bol} = 0.46 - 4.17 \log P_{tr} .$$

Using this formula, we find that the RR Lyrae variables in the type I clusters are brighter by a 0.1 mag. than in the type II clusters.

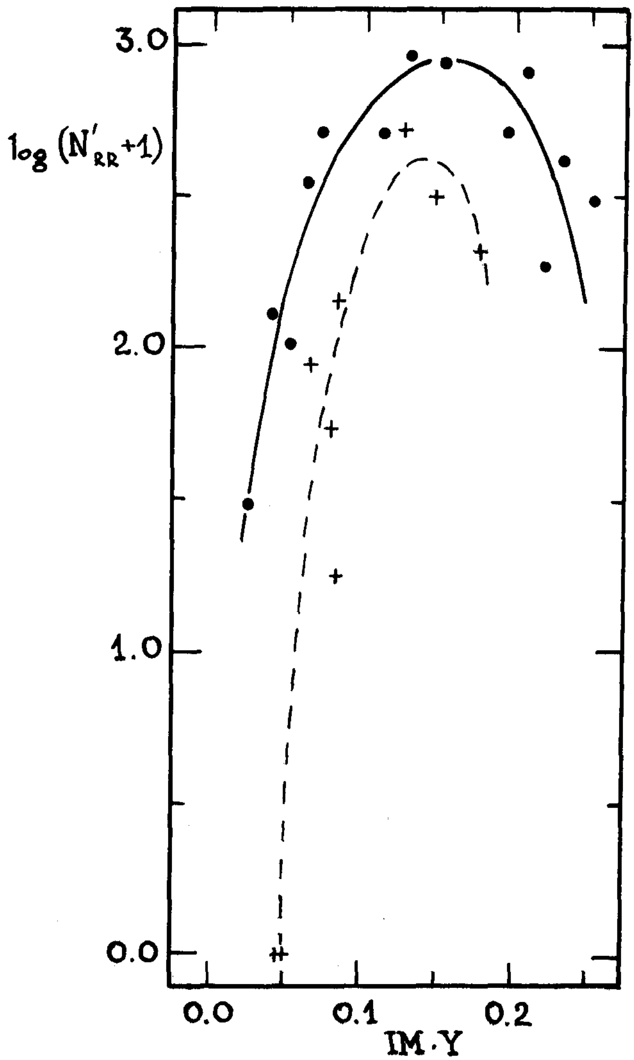

Fig. 3. Relative richness of RR Lyrae population in clusters as a function of chemical abundance. Symbols as in Figure 1.

The ninth and tenth columns are analogous to the fifth and sixth columns, respectively, but relate now to W Virginis variables. Because of the small number of these variables in individual clusters, no reliable conclusions can be drawn. Nevertheless our work confirms Wallerstein's (1970) conclusion that the W Vir variables do not occur in clusters of relatively high metallicity. Besides, the relation between the helium abundance Y and the value of N'_{cw} is interesting, as Figure 4 shows, N'_{cw} decreases as Y increases.

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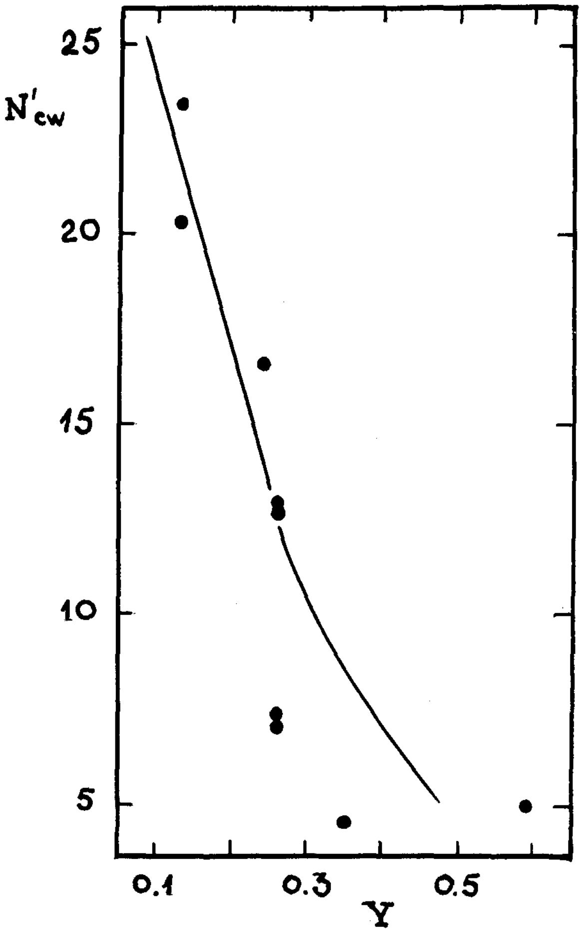

Fig. 4. The dependence of numbers of W Vir stars on helium abundance.

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