PART 10

RR LYRAE AND W VIRGINIS STARS

RR LYRAE- AND W VIRGINIS-TYPE STARS

B. V. KUKARKIN

Sternberg Astronomical Institute, Moscow, U.S.S.R.

Abstract. RR Lyrae stars: Normalized period-frequency diagrams are discussed, see Table I and Figure 1. Two 'standard' period-frequency relations were derived: one for $[m/\mathrm{H}] \geqq -1.17$ and the other for $[m/\mathrm{H}] \leqq -1.72$. The peculiarity of the diagrams for some clusters is pointed out. Various metallicity criteria are discussed together with other features of globular clusters. Some unexplained anomalies are found.

W Virginis stars: Properties of these stars are discussed. They too seem not to form a homogeneous group. The lack of accurate observations is stressed.

The investigation of RR Lyrae- and W Virginis-type stars during the last 20 years has shown undoubtedly that these objects do not constitute homogeneous groups and are mixtures of representatives of different age and origin. Step by step the confidence that all the RR Lyrae stars have the same absolute magnitude, $0\overset{m}{.}0$, and that W Vir stars satisfy the usual period-luminosity relation for Cepheids was replaced by the certainty of the diversity of the former and that the latter are quite different from the classical Cepheids of the flat component of our Galaxy, the Magellanic Clouds, M 31 and M 33.

As early as the forties it was pointed out that the Cepheids in globular clusters are similar to W Vir stars. In the fifties nobody had any doubt about it (see for instance Kukarkin and Kulikovsky, 1951). Pavlovskaya (1953) made it obvious that absolute magnitudes of RR Lyrae stars are near $+0\overset{m}{.}5$ with considerable dispersion.

We do not attempt to present a complete review of all the features of RR Lyr and W Vir stars in this paper. Recently a lot of reviews on these stars concerned with observational results as well as with theoretical studies have been published, so there is no reason to repeat all this information. Here are the references to some papers that seem to us most interesting (for full references see the end of the paper): Ledoux and Walraven (1958), Christy (1966), Tsessevich, (1966), Frolov (1970), Tsessevich (1970), Hoffmeister (1970), Iben (1971), Strohmeier (1972), Rosino (1973), Kukarkin (1974a).

1. RR Lyrae-Type Stars

In the last 20 years astronomers have become more and more assured that RR Lyrae stars do not constitute a homogeneous group of objects. It has been known for a long time that the group of stars with particularly short periods is characterized by significantly lower luminosity (from $+2^m$ to $+4^m$) and relatively high (practically normal) metallicity. δ Scuti stars surely form an isolated group, too. The existence of two groups of RR Lyrae variables in globular clusters was pointed out by Oosterhoff (1939), and the almost complete absence in globular clusters of stars with periods near $0\overset{d}{.}42$ was pointed out by Kholopov and by Kukarkin (1947, 1949).

When working on the problem of period-frequency relations for RR Lyrae stars,

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one should take into account that the catalogue of variable stars in our Galaxy (Kukarkin *et al.*, 1969–1971) as well as the catalogue of variable stars in globular clusters (Sawyer Hogg, 1973) contain a lot of spurious periods of RR Lyrae stars. Recently Shugarov of Moscow University (private communication) investigated 11 RR Lyrae stars with periods $<0\overset{\mathrm{d}}{.}36$, but with highly asymmetric light curves typical of RRab subtype. Periods were found to be correct only in two cases; in nine cases correct periods were found to be near $0\overset{\mathrm{d}}{.}5$–$0\overset{\mathrm{d}}{.}6$.

Let us try to give some examples that show the non-homogeneity of the samples of RR Lyrae variables in different isolated stellar systems. Table I gives normalized

TABLE I

Normalized frequencies of periods of RR Lyrae stars in globular clusters and in dwarf galaxies

NGC	3201	4590	5024	5139	5272	5466	5904	6121
n	80	37	40	140	183	21	88	40
[*m*/H]	−1.36	−1.95	−1.75	−1.52	−1.44	−1.87	−1.34	−1.11
Periods								
0.200–0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025
0.250–0.299	0.037	0.027	0.000	0.029	0.044	0.047	0.068	0.100
0.300–0.349	0.075	0.027	0.100	0.129	0.076	0.143	0.171	0.100
0.350–0.399	0.037	0.514	0.300	0.172	0.038	0.191	0.023	0.000
0.400–0.449	0.000	0.054	0.000	0.071	0.016	0.048	0.011	0.075
0.450–0.499	0.050	0.000	0.000	0.043	0.137	0.000	0.182	0.175
0.500–0.549	0.363	0.000	0.075	0.071	0.361	0.047	0.227	0.046
0.550–0.599	0.238	0.162	0.000	0.114	0.169	0.143	0.171	0.100
0.600–0.649	0.175	0.081	0.300	0.128	0.109	0.143	0.091	0.175
0.650–0.699	0.025	0.081	0.075	0.100	0.027	0.048	0.034	0.000
0.700–0.749	0.000	0.054	0.100	0.036	0.006	0.095	0.011	0.000
0.750–0.799	0.000	0.000	0.025	0.043	0.006	0.048	0.000	0.000
0.800–0.849	0.000	0.000	0.025	0.043	0.000	0.047	0.011	0.000
0.850–0.899	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000

NGC	6171	6266	6402	6656	6715	6723	6934	6981
n	22	73	34	18	30	27	30	28
[*m*/H]	−0.79	−0.99	−1.12	−1.72	−1.17	−0.79	−1.42	−1.42
Periods								
0.200–0.2.49	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000
0.250–0.299	0.227	0.041	0.029	0.000	0.000	0.037	0.000	0.000
0.300–0.349	0.136	0.082	0.000	0.222	0.033	0.111	0.000	0.000
0.350–0.399	0.000	0.014	0.059	0.166	0.033	0.000	0.000	0.036
0.400–0.449	0.045	0.069	0.000	0.111	0.067	0.037	0.000	0.036
0.450–0.499	0.182	0.246	0.118	0.000	0.100	0.222	0.167	0.143
0.500–0.549	0.046	0.165	0.353	0.056	0.333	0.334	0.433	0.250
0.550–0.599	0.318	0.219	0.147	0.000	0.300	0.111	0.233	0.392
0.600–0.649	0.000	0.082	0.147	0.333	0.067	0.111	0.167	0.107
0.650–0.699	0.000	0.014	0.147	0.056	0.067	0.037	0.000	0.036
0.700–0.749	0.046	0.027	0.000	0.056	0.000	0.000	0.000	0.000
0.750–0.799	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000
0.800–0.849	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.850–0.899	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table I (Continued)

NGC or galaxy	7006	7078	Leo II	Scl	UMi	Dra
n	55	65	65	60	40	137
[m/H]	−1.48	−2.00	–	–	–	–
Periods						
0.200–0.249	0.000	0.000	0.000	0.000	0.000	0.007
0.250–0.299	0.018	0.046	0.000	0.067	0.075	0.000
0.300–0.349	0.000	0.046	0.031	0.050	0.075	0.014
0.350–0.399	0.000	0.338	0.062	0.033	0.100	0.015
0.400–0.449	0.018	0.123	0.031	0.000	0.100	0.029
0.450–0.499	0.091	0.016	0.015	0.083	0.050	0.014
0.500–0.549	0.218	0.000	0.184	0.350	0.050	0.044
0.550–0.599	0.473	0.154	0.339	0.200	0.050	0.343
0.600–0.649	0.164	0.092	0.246	0.117	0.250	0.358
0.650–0.699	0.018	0.123	0.062	0.067	0.150	0.153
0.700–0.749	0.000	0.046	0.015	0.017	0.017	0.015
0.750–0.799	0.000	0.016	0.000	0.000	0.000	0.015
0.800–0.849	0.000	0.000	0.015	0.016	0.000	0.000

RR Lyrae period-frequency relations for several globular clusters of our Galaxy and for several dwarf galaxies. Histograms for globular clusters of our Galaxy are based mainly on data from Sawyer Hogg's (1973) catalogue; in several cases we added new data (for the cluster M 53 according to Goranskij (1974), for the cluster NGC 6723 according to Menzies (1974)). Period-frequency relations for dwarf galaxies are based mainly on van Agt's (1973) data with the addition of data by Kholopov (1971) only for the galaxy in Ursa Minor. The first line of the table gives the designation of the cluster or the dwarf galaxy, the second line gives the number of RR Lyrae stars with known periods, and the third line gives the metal abundance [m/H] according to my data which are continuously being improved. Then we give the normalized numbers of RR Lyrae variables in the intervals given in the left column of the table. All period-frequency diagrams are shown in Figure 1.

Two 'standard' period-frequency relations were derived: one for globular clusters with intermediate metallicity ([m/H]$\geqslant -1.17$) and another for clusters with the lowest metallicity ([m/H]$\leqslant -1.72$). It is known that there are no RR Lyrae stars in the clusters with high metallicity. All the variables in the clusters that form the first 'standard' relation belong to the Oosterhoff I type, and those forming the second 'standard' relation belong to the Oosterhoff II type. Similar histograms were obtained by Rosino (1973). The 'standard' relations and corresponding numbers are given in Table II and shown in Figure 2. The same table and figure also give the period-frequency relations for the stars in the galactic field and for all the dwarf galaxies.

Period-frequency relations for every individual stellar system from Table I and for our Galaxy were recently compared by Pavlovskaya with our 'standards' by means of Pearson's criterion. The majority of stellar systems are in accordance with the 'standard' type of clusters of intermediate metallicity; for example, NGC 5272, 5904, 6121, 6266, 6402, 6715, 6723, 6934, 6981, Sculptor galaxy and, less confidently, NGC 3201

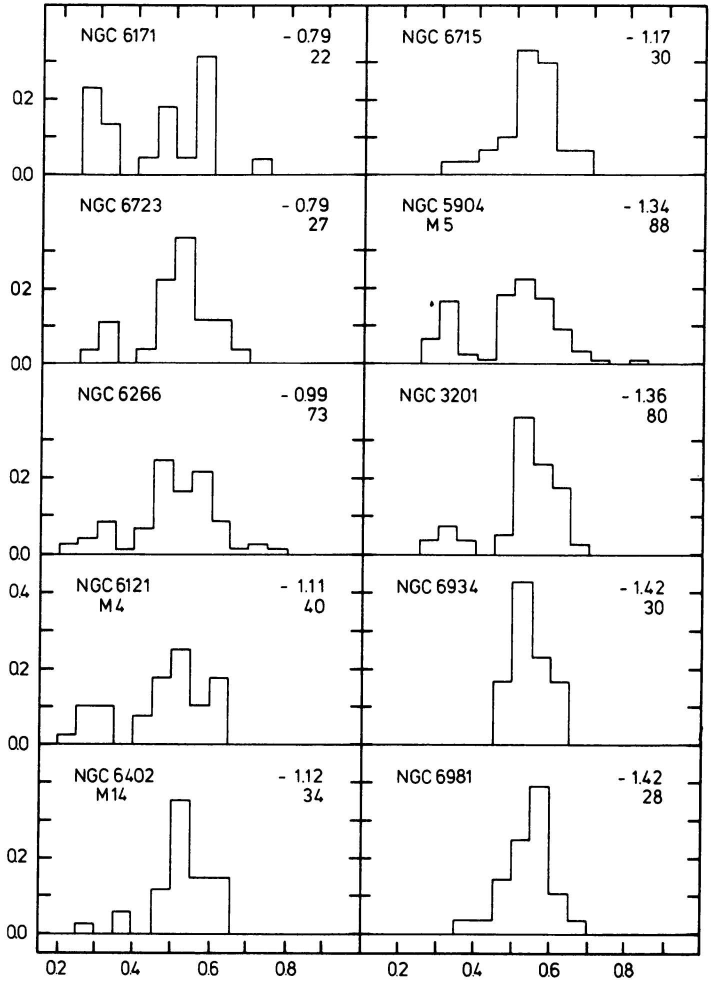

Fig. 1a. Period-frequency diagrams for RR Lyrae stars in globular clusters and dwarf galaxies. The name of the stellar system is given in the upper left corner of every diagram. The value of metallicity [*m*/H] and the number of RR Lyrae stars are also given in the upper right corner.

and 6171. A smaller number of systems is in accordance with low-metallicity 'standard'; these are NGC 4590, 5024, 5466, 6656, 7078, and the galaxy in Ursa Minor. But systems were also found that are in accordance with neither of the 'standards'. These are our Galaxy, the galaxies Leo II and Draco, NGC 7006, and, less confidently, NGC 5139.

It should be kept in mind that for poorly studied systems there may be an apparent deficiency of RRc stars. But this deficiency is reflected by 'standard' relations to some extent. The inconsistency of the relations may be explained partly by the mixture of stars of both Oosterhoff groups. But for the systems like ω Cen and the Galaxy, this explanation does not work since the ratio of the numbers of stars with different

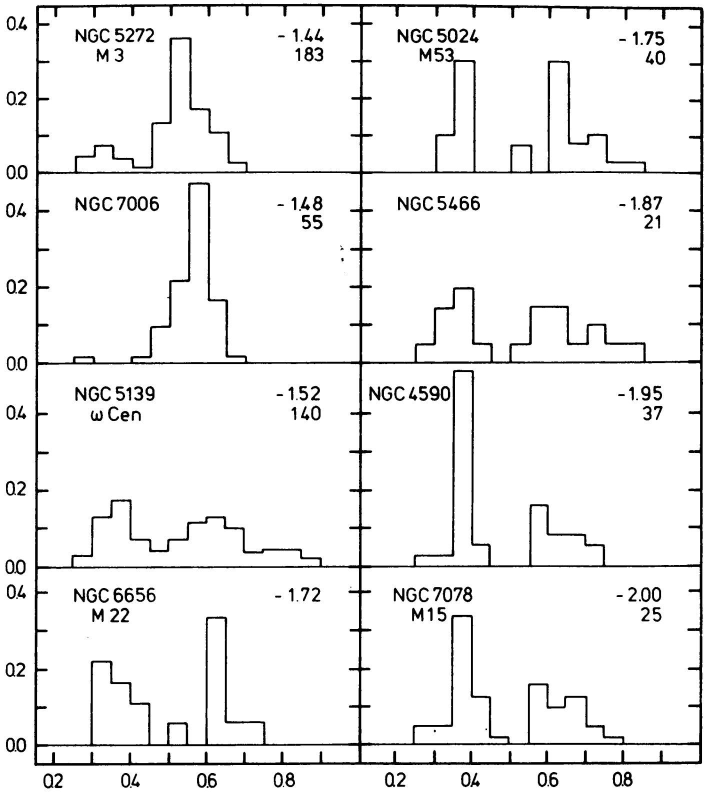

Fig. 1b. The continuation of Figure 1a.

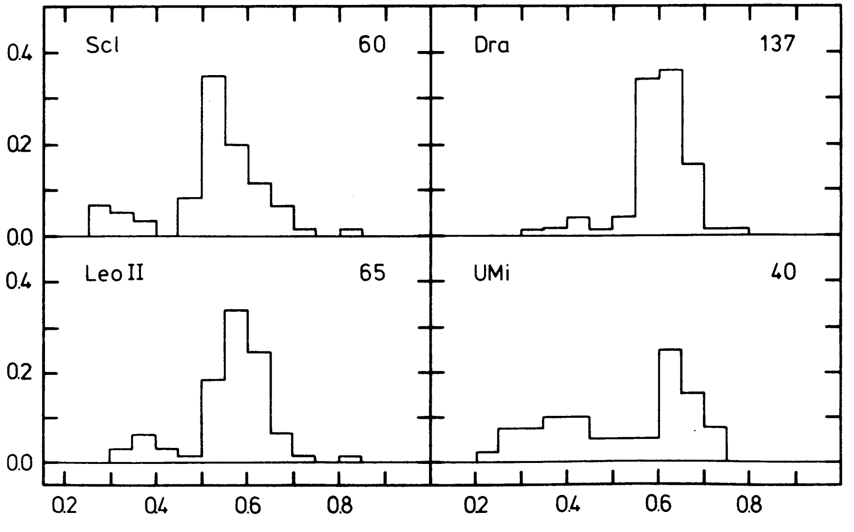

Fig. 1c. The continuation of Figure 1a.

periods cannot be explained by a simple mixture. For example, in our Galaxy RR Lyrae stars show a very large frequency excess near the period $0^{d}.42$. Probably a considerable fraction of the galactic field stars with periods $< 0^{d}.45$ originated under conditions quite different from those in globular clusters. We shall see now that the majority of these stars have high metallicity and almost circular orbits.

TABLE II

Normalized frequencies of periods of RR Lyrae stars in globular clusters of intermediate and low metallicity in our Galaxy and in dwarf galaxies

[*m*/H]	Globular clusters $\geqslant -1.17$	Globular clusters $\leqslant -1.72$	Our Galaxy –	Dwarf galaxies –
Periods				
0.200–0.249	0.015	0.004	0.008	0.004
0.250–0.299	0.058	0.032	0.023	0.025
0.300–0.349	0.077	0.086	0.046	0.032
0.350–0.399	0.031	0.276	0.056	0.039
0.400–0.449	0.054	0.068	0.085	0.025
0.450–0.499	0.200	0.014	0.194	0.032
0.500–0.549	0.239	0.032	0.196	0.128
0.550–0.599	0.177	0.131	0.181	0.290
0.600–0.649	0.096	0.190	0.115	0.272
0.650–0.699	0.038	0.090	0.056	0.118
0.700–0.749	0.011	0.059	0.025	0.021
0.750–0.799	0.004	0.009	0.008	0.007
0.800–0.849	0.002	0.008	0.003	0.007
0.850–0.899	0.001	0.002	0.003	0.000

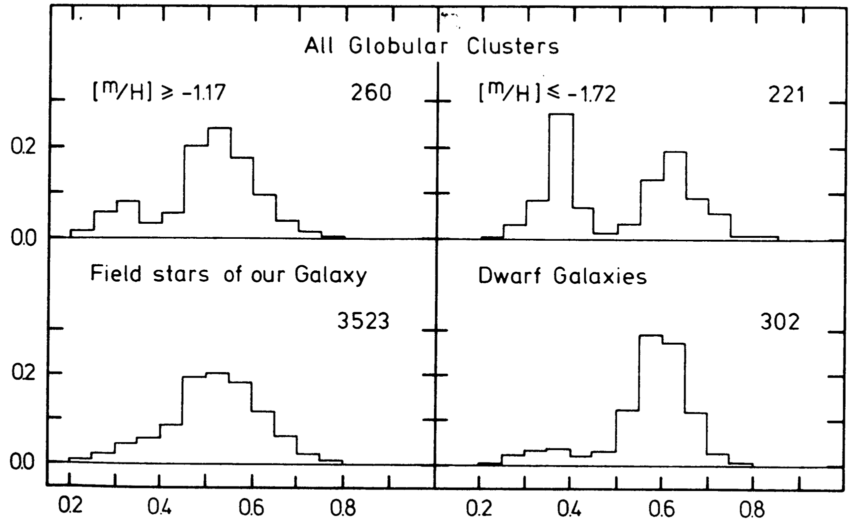

Fig. 2. The 'standard' period-frequency diagrams of RR Lyrae stars. *Above*: for the globular clusters with the value $[m/\mathrm{H}] \geqslant -1.17$ (left) and for the globular clusters with $[m/\mathrm{H}] \leqslant -1.72$ (right). *Below:* for galactic field stars (left) and for all the studied dwarf galaxies (right).

Struve (1950) pointed out that the kinematic characteristics of RR Lyrae stars correlate with the period. This is evidence that the conditions of the origin and evolution of these stars are different. But even before the publication of Struve's paper a number of facts were known that suggested the diversity of physical characteristics of RR Lyrae stars. Münch and Terrazas (1946) were the first to point out the different chemical compositions of the atmospheres of several RR Lyrae stars. Soon the significance of these facts for the problems of stellar cosmogony was emphasized (Kukarkin, 1947, 1949). Iwanowska (1953) confirmed the diversity of chemical composition. Further development of these ideas was due to Preston (1959) who investigated many dozens of RR Lyrae stars. He introduced a quantitative measure of metal abundance, ΔS. Later the dispersion of the quantity $\delta(U-B)$ which is also related to metal abundance was discovered (see for instance Clube, 1969). A recent study by Jones (1973) deserves special attention. By means of intermediate-band photometry he obtained indices $(k-b)_2$ which characterize confidently metal abundances in the atmospheres of RR Lyrae stars. Recently in Moscow, Pavlovskaya and Karimova reduced all the determinations of different measures of metal abundance $[\Delta S, \delta(U-B)]$ to the system $(k-b)_2$. Weighted mean values were calculated. These values were compared with the elements of osculating orbits of RR Lyrae stars; these elements were calculated for the stars with the most reliable determinations of radial velocities and proper motions. The results are plotted in Figures 3 and 4; the basic parameters of the two stellar groups are given in Table III. One may clearly see that the relatively metal-rich RR Lyrae stars have small orbital inclinations. The inclination (in radians) exceeds 0.50 for only one star, whereas any values of inclination may be found among metal-poor stars. One can also see clearly that the relatively metal-rich stars have

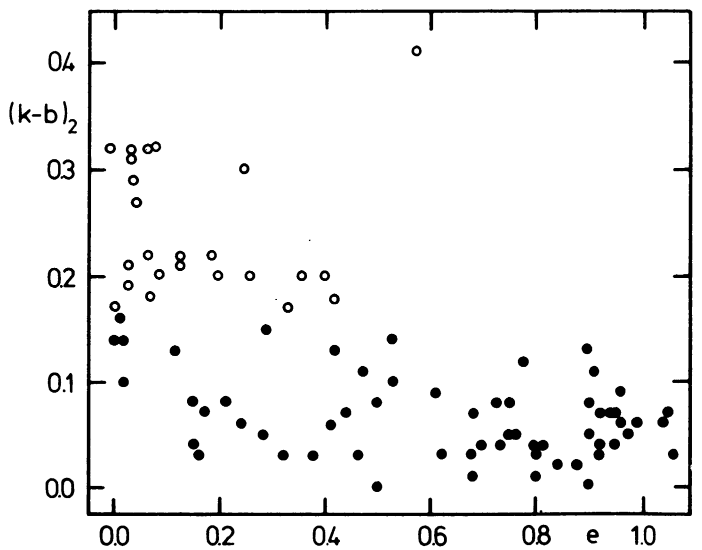

Fig. 3. Eccentricities of osculating orbits of galactic field RR Lyrae stars versus metallicity. Circles designate stars with high metal abundance and crosses designate stars with low metal abundance.

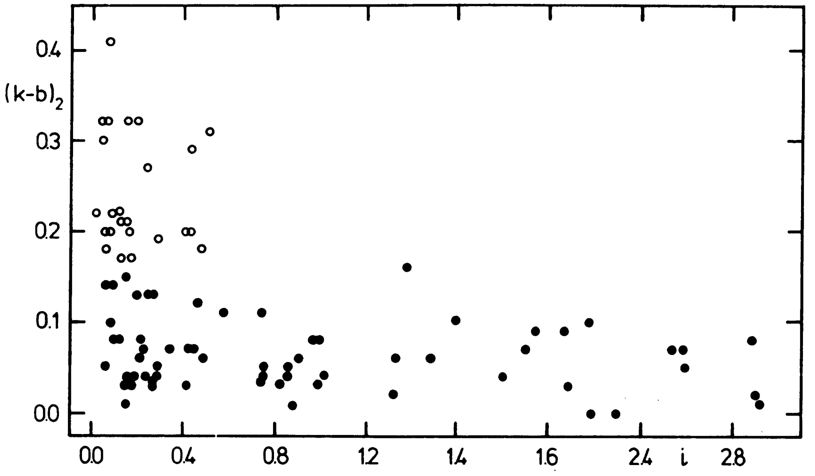

Fig. 4. Inclinations of osculating orbits of galactic field RR Lyrae stars vs metallicity. The designations are the same as in Figure 3.

TABLE III

General parameters of two groups of globular clusters according to their metallicity $(k-b)_2$

	Group I	Group II
	○	●
$\overline{(k-b)_2}$	0.25	0.07
N	24	62
$\bar{P}$	0^d415	0^d575
$\bar{e}$	0.18	0.66
$\bar{i}$	0.16	0.98
Ang. vel. at distance of the Sun	23 km s^{-1}	9 km s^{-1}
σ_1	26 ± 6	86 ± 8
σ_2	40 ± 3	95 ± 9
σ_3	30 ± 6	160 ± 11

smaller eccentricities and the metal-poor stars may have any eccentricities, up to hyperbolic orbits. This is not only evidence for the diversity of galactic orbits of RR Lyrae stars; it is obvious that the relatively metal-rich stars belong to disc population and the metal-poor stars belong to halo population. Hence their origin is quite different, in spite of the similar phenomenon of variability.

We can find many examples of different unexplained anomalies. For instance, why are RR Lyrae stars practically absent in the globular cluster M 13 whereas they are very abundant in the cluster ω Centauri which has a similar colour-magnitude diagram? Why do several metal-poor clusters show relatively high abundance of RR Lyrae variables (M 15, NGC 4590, 5053, 5466) whereas they are totally absent in some other clusters (M 10, M 12, M 56, NGC 6397)?

Figure 5 shows the dependence of the number of RR Lyrae variables in different globular clusters on their metallicity (abscissa) according to the data from the new catalogue of globular clusters (Kukarkin, 1974b) and the catalogue of variable stars in globular clusters (Sawyer Hogg, 1973). N is the number of RR Lyrae stars in a given cluster reduced to the standard absolute magnitude $M_V = -7\overset{m}{.}5$. One can see that globular clusters may be separated into three rather distinct groups on the basis of the frequency of RR Lyrae stars.

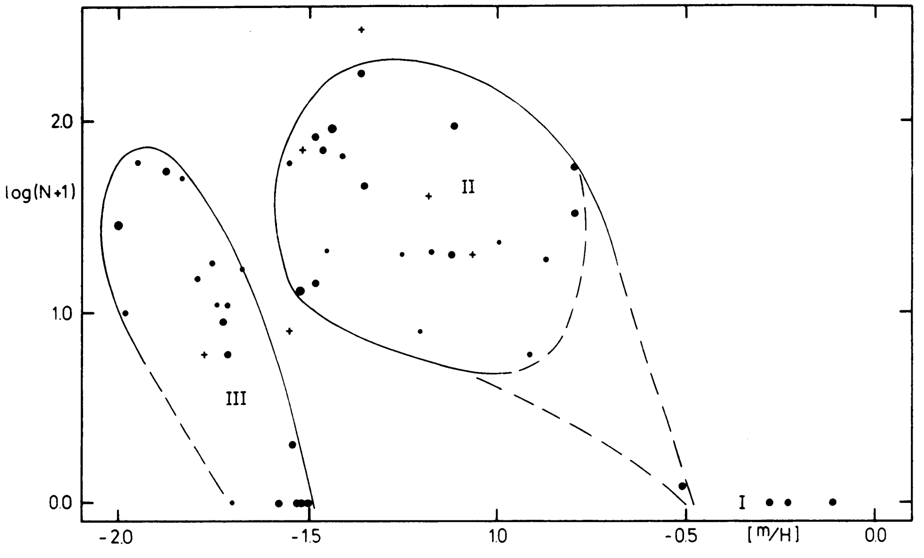

Fig. 5. Frequency of RR Lyrae stars in globular clusters vs [m/H]. The diameters of the circles approximately correspond to the accuracy of the co-ordinates. Crosses designate clusters with uncertain co-ordinates.

Recently Basharina, Pavlovskaya and Filippova carried out the modelling of the light curves of RR Lyrae variables in four globular clusters (their method is described in the article by Basharina *et al.*, 1972). It was assumed that, in spite of considerable difference between individual light curves of RR Lyrae stars in a given cluster, they all are the manifestation of a single process of pulsation. Correlations between various characteristics of observed light curves and analogous correlations obtained by means of modelling with an electronic computer were studied. The comparison of the obtained estimates of correlation coefficients makes it possible to judge how successful the modelling of the variability process in a given cluster was. The results are given in Table IV and in Figure 6. One can see that for three clusters the percentage of inconsistencies decreases monotonously and for one cluster it has a maximum. This means that the light curves in the clusters NGC 3201, M 3 and M 5 may be considered as individual realizations of a Gaussian process. However, this cannot the concluded for the light curves in the cluster ω Centauri. This is one more piece of evidence for the striking variety of the origin of stars even inside a single globular cluster.

TABLE IV

The percentage of inconsistencies of light curves with the model

NGC	The number of inconsistencies								
	0	1	2	3	4	5	6	7	8
3201	49.0	30.2	7.3	8.3	3.1	2.1	0.0	0.0	0.0
5139	0.0	2.5	16.7	28.3	30.0	16.7	3.3	1.7	0.8
5272	47.2	24.8	13.6	8.0	2.4	1.6	1.6	0.8	0.0
5904	33.3	23.7	21.1	11.4	7.0	3.5	0.0	0.0	0.0

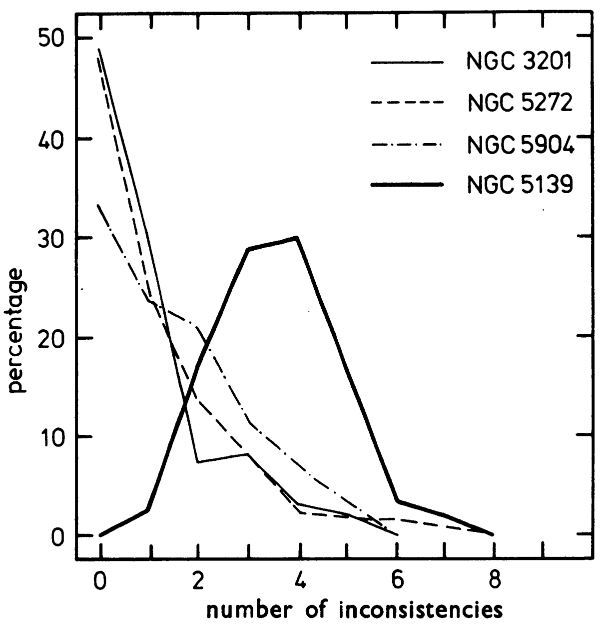

Fig. 6. *Abscissa:* the number of significant deviations from the model; *ordinate:* the corresponding percentage of the light curves in a given cluster (shown by different types of lines).

During recent years it has been stated several times that RR Lyrae stars may have periods exceeding 1 day and, conversely, W Vir stars may have periods shorter than 1 day (van Agt, 1967; Swope, 1968; Kholopov, 1971; Mandel, 1971). Unfortunately this problem is poorly studied and needs careful investigation; additional difficulty for this study arises from the fact that the kinematics of these stars have not been sufficiently investigated.

It is quite obvious that the variety of RR Lyrae stars is rather wide and there exist many other features, apart from Oosterhoff's two groups.

The attempted two-dimensional classification of globular clusters by Hartwick (1968) and its modification by Italian astronomers (Castellani *et al.*, 1970) proved to be unsuccessful. Mironov's classification (Mironov and Samus', 1974) seems to be more convincing. It fits the separation of globular clusters according to the frequency of RR Lyrae stars (see Figure 5). But this classification also does not reflect details and does not explain some anomalies. *It is necessary to continue the search for additional criteria.* During this search it is especially significant to investigate thoroughly RR Lyrae stars in globular clusters of different age and different metallicity. We may consider it firmly established that RR Lyrae stars are entirely absent in relatively metal-rich globular clusters. Several stars in the cluster NGC 6304, however, were attributed to RR Lyrae type in Sawyer Hogg's catalogue (1973) in accordance with the paper by Rosino (1962). But an examination of Rosino's paper gives grounds for the suggestion that these are all field stars and not cluster members.

Further investigation of the dynamic characteristics of globular clusters is very interesting and important. But one should be very careful. We saw in Figures 3 and 4 that there exists a well-defined relation between eccentricities and inclinations of galactic orbits, on the one hand, and cluster metallicities, on the other hand. Lower limits of the eccentricities of globular cluster orbits (Peterson, 1974) did not show a correlation with metallicity.

Almost fifteen years ago a successful reconnaissance of the problem of stellar dissipation from globular clusters was undertaken by Kurochkin (1961, 1962). The study of the spatial densities of RR Lyrae stars in the vast surroundings of several globular clusters enabled Kurochkin to conclude that the density increases when we approach clusters rich in variable stars. He tentatively estimated that about $\frac{1}{3}$ of the total number of RR Lyrae stars in the galactic field could originate by dissipation from globular clusters while $\frac{2}{3}$ could not have origins related to globular clusters. A more accurate solution of this extremely interesting problem requires further observations of the surroundings of as many globular clusters rich in RR Lyrae stars as possible. Such an investigation has been started in Italy (Rosino, 1970).

It is very interesting to investigate the changes of periods of RR Lyr- and W Vir-type variables. This is of particular importance for the development and testing of the theory of their evolution (see for instance Schwarzschild, 1970; Iben, 1971). Iben and Rood (1970) correctly stated that the so-called 'secular' variations of the periods of RR Lyrae stars (the quantity β) are a kind of noise. Interesting investigations were undertaken by Tsessevich (1966) who studied different kinds of period variations of RR Lyrae stars and the relationships between these variations and different groups of these stars.

After Zhevakin's pioneer studies which were followed by Christy and others, the theory of stellar pulsations developed considerably. The progress in the field of computation of evolutionary tracks for horizontal branch stars was also great. The results by different authors who made somewhat different assumptions are in satisfactory agreement. It is possible to suppose on the basis of these investigations that the periods of RR Lyrae stars can increase and decrease in the course of evolution when the star crosses the instability strip in different directions (see for instance Goranskij, 1973). If we had succeeded in separating the real evolutionary period variations from noise, we would possibly have obtained invaluable information for the development of the theory of the evolution of stars with masses less than 1 $\mathfrak{M}_{\odot}$. Unfortunately we are now still very far from the accurate solution of this problem even in the observational aspect. It is necessary to continue to observe every year selected RR Lyrae stars in the galactic field and in several globular clusters especially rich in variables and differing in metallicity (the extreme cases in this respect are the metal-poor clusters NGC 6341 and 7078 and relatively metal-rich clusters NGC 6171 and 6723). If such observations are organized, we shall surely discover within a few decades evolutionary trends in the period variations of RR Lyrae stars.

The systematic observation of all the constant stars in the instability strip is also an important task. Several cases when such observations led to the discovery of new variables are already known (Gryzunova, 1972; Wehlau and Potts, 1972). But there are also some examples of the presence of undoubtedly constant stars in the instability strip (see for instance Dickens and Rolland, 1973). It is necessary to prove that these stars are cluster members and to study their characteristics carefully. It is also necessary to undertake careful investigation of the stars near the boundaries of the instability strip. The indifference to this problem is surprising. Since the discovery of two small-amplitude variables at the red and the blue boundaries of the M 3 instability strip by Roberts and Sandage (1955) *nobody* has investigated these stars to confirm or to disprove Roberts and Sandage's results. The search for variable stars at the instability strip boundaries should be continued. It is also necessary to determine reliable positions of the red and the blue boundaries of the instability strip by means of accurate photometry since these values have been determined reliably for only half a dozen globular clusters. The accurate fixing of these boundaries is extremely significant for checking theoretical conceptions as well as for practical purposes (estimates of interstellar reddening, etc.). In recent years Voroshilov at the Southern Station of the Sternberg Astronomical Institute discovered small-amplitude variable stars near the instability strip (see the section devoted to W Vir stars).

Thorough investigation of selected RR Lyrae stars in the nearest (but differing in their characteristics) globular clusters will be of great value. We mean multicolour photometry, spectroscopy with highest possible dispersion for the determination of radial velocities as well as for the study of atmospheres, proper motions, etc. This problem is clearly a difficult one and it cannot be solved without large telescopes. But the continuous growth of the number of such telescopes gives us good hope for the future.

2. W Virginis-Type Stars

Similar to RR Lyrae stars, it was found that W Vir stars do not constitute a homogeneous group of objects. Till the middle of the sixties all these stars were thought to be galactic halo objects. However, Woolley (1966) showed convincingly that the kinematic properties of these stars do not correspond to the kinematics of globular clusters. The velocity dispersion was found to be considerably less than for globular clusters. This is quite convincing evidence for the independent origin of globular clusters and a considerable percentage of field W Vir stars.

Even before Woolley's publication, Vasilyanovskaya *et al.* (1966) pointed out the necessity of the separation of W Vir stars into two groups. Kwee (1967, 1968) and Kwee and Braun (1967) suggested another version of the separation into groups. Vasilyanovskaya and Erleksova (1968) pointed out that there exists a difference in the instability of periods for the two groups of W Vir stars. All these facts provide evidence that only a part of W Vir stars may have originated from the dissipation of globular clusters. The origin of the majority of these stars is different from the origin of globular clusters.

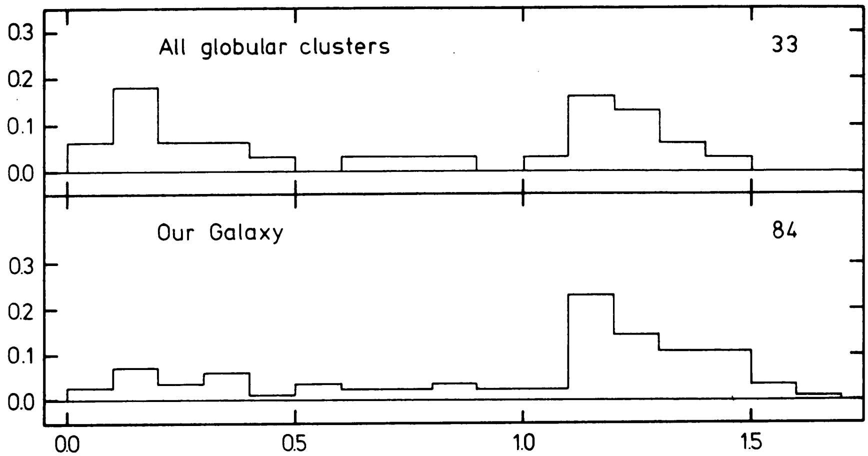

Fig. 7. Period-frequency diagrams for W Vir stars in globular clusters (above) and in the galactic field (below).

The distribution of cluster W Vir stars and of field W Vir stars according to different characteristics is very significant. The easiest task is to study period-frequency diagrams for the stars of this type. Figure 7 shows normalized period-frequency distribution for the stars in globular clusters (above) and in the galactic field (below). The separation into a short-period and a long-period group is distinctly seen. This separation is more distinct in globular clusters. But one should not forget that the selection effects are different for the galactic field and for globular clusters. Nearly all the W Vir variables in globular clusters have already been discovered since they are always among the brightest stars on unsensitized plates. For the same limiting magnitude in the galactic field we see the long-period W Vir stars in a volume of space that is much greater than for the short-period W Vir stars since the latter are considerably fainter.

Long ago Arp (1955) noticed that some stars of the long-period group in globular clusters show the RV Tauri effect (even and odd minima are of different depth), so the period should be doubled. Thus even in globular clusters where in every cluster all the stars were formed together and probably with a rather small dispersion of ages we meet a variety of properties. Soon after, RV Tauri effect was found for some W Vir stars in the galactic field.

It is desirable to determine radial velocities for as many W Vir stars as possible in the galactic field as well as in globular clusters. It will enable us to study the kinematics of different subtypes of W Vir stars in the galactic field and also to state with confidence their membership in the globular clusters.

Unfortunately the number of W Vir stars in globular clusters with known periods and at least rough light curves hardly exceeds 30. This sample is not sufficient for reliable statistic investigations, especially with separation into groups according to certain characteristics. It is necessary to appeal to all the observatories possessing plates of globular clusters for the investigation of all the suspected variables that have apparent magnitudes considerably brighter than those of horizontal branch stars and are not characterized by large values of $(B-V)$. These stars are very likely to turn out to be W Vir stars. There exist 15 globular clusters with about 30 stars satisfying this criterion.

Wallerstein (1970) noticed four peculiarities characteristic of the globular clusters that contain W Vir stars. The increase of the number of clusters with known W Vir stars will certainly contribute to more accurate knowledge of the conditions that make it probable that these stars appear in a globular cluster.

The attempts to explain theoretically the presence of these stars in globular clusters (Schwarzschild and Härm, 1970; Mengel, 1973) are unlikely to correspond to reality. According to Schwarzschild and Härm, the masses of W Vir stars must be less than the masses of RR Lyrae stars. But it is known that RR Lyrae stars are found in the most distant parts of cluster coronae whereas no W Vir stars are known at such a great distance from the centres of globular clusters. And the probability of the discovery is higher for W Vir stars than for RR Lyrae stars! The spatial density gradient for RR Lyrae stars in globular clusters is considerably less than for W Vir stars; this is also an argument for greater masses of the latter (Kukarkin and Voroshilov, 1971).

Theoretic computations suggest relatively short time intervals for the presence of W Vir stars in the instability strip. However, the investigations by Coutts (1973) and Rastorgouev (1974) seem to indicate relative stability of periods for the majority of W Vir stars in globular clusters when compared with galactic field stars κ Pavonis and AP Herculis. Constant attention to the W Vir stars in globular clusters is necessary in order to make possible in the next few decades a reliable investigation of their period variations.

Long ago van Agt (1967) and later Kholopov (1971) pointed out that, in globular clusters and dwarf galaxies, there exist stars with periods <1 day, but much brighter than RR Lyrae stars. Probably they are all short-period W Vir stars. Such stars are also present in the galactic field, but we are not able to distinguish them from RR Lyrae stars yet. Recently Zinn (1974) showed that the star V 19 in the globular cluster NGC 5466 ($P = 0\overset{d}{.}82$) is not a foreground star at all, but is a cluster member since its radial velocity is equal to that of the cluster itself. This star is approximately 1.5 mag. brighter than the RR Lyrae stars!

Figure 8 shows the areas of the period-luminosity diagram occupied by classical

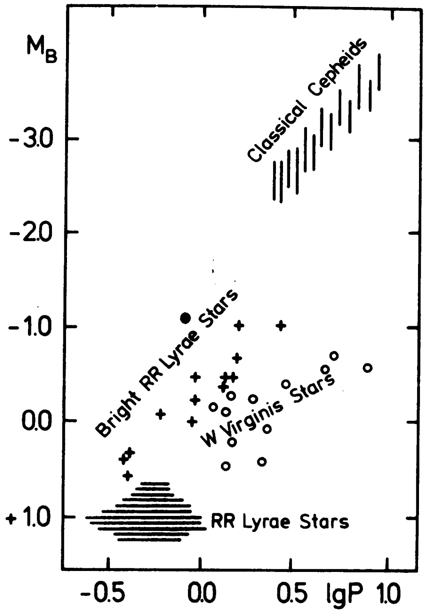

Fig. 8. The period-luminosity relation. The position of W Vir stars in globular clusters is shown by open circles (○) and the position of variables with increased luminosity in globular clusters and dwarf galaxies is shown by crosses (+). The position of the star V 19 in NGC 5466 is shown by a circled cross. The shading shows the areas occupied by classical Cepheids and by normal RR Lyrae stars.

Cepheids (vertical shading) and by RR Lyrae stars (horizontal shading); W Vir stars in globular clusters are plotted as circles, RR Lyrae stars of higher luminosity in globular clusters are plotted as crosses. One can see that the latter do not occupy the same region as W Vir stars. Probably it is necessary to pay more attention to studies of these stars and their peculiarities. The position of the star V 19 in the cluster NGC 5466 is most striking (the circled cross).

The facts discussed in the present paper are undoubtedly evidence for the non-homogeneity of RR Lyr and W Vir stars in the galactic field as well as in globular clusters. The supposition that this variety is connected with repeated transit of the instability strip and with different initial conditions seems probable.

This paper has touched only some of the problems that arise from the studies of RR Lyr and W Vir stars. During the preparation of the paper we tried to concentrate on such problems that their investigation could give valuable and sufficiently definite results just now. The investigation of these objects in the Magellanic Clouds and the Andromeda nebula (M 31) seems to be very important. Only the first steps in this direction have so far been made. When planning the studies with new giant telescopes which are now coming into operation, one should not forget the great value of the studies of Cepheids and RR Lyrae stars for the development of modern cosmogony and cosmology.

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Many thanks are due to D. K. Karimova, N. N. Kireeva, N. P. Kukarkina, E. D. Pavlovskaya and N. N. Samus' for diverse assistance during the preparation of this review.

References

Agt, S. L. Th. van: 1967, *Bull. Astron. Inst. Neth.* **19**, 275.
Agt, S. L. Th. van: 1973, in J. D. Fernie (ed.), *Variable Stars in Globular Clusters and in Related Systems*, D. Reidel Publ. Co., Dordrecht, p. 35.
Arp, H. C.: 1955, *Astron. J.* **60**, 1.
Basharina, T. S., Pavlovskaya, E. D., and Filippova, A. A.: 1972, *Variable Stars*, **18**, 367.
Castellani, V., Giannone, P., and Renzini, A.: 1970, *Astrophys. Space Sci.* **9**, 418.
Castellani, V., Giannone, P., and Renzini, A.: 1973, in J. D. Fernie (ed.), *Variable Stars in Globular Clusters and in Related Systems*, D. Reidel Publ. Co., Dordrecht, p. 197.
Christy, R. F.: 1966, *Astrophys. J.* **144**, 108.
Clube, S. V. M.: 1969, *Mem. Roy. Astron. Soc.* **72**, 101.
Coutts, C. M.: 1973, in J. D. Fernie (ed.), *Variable Stars in Globular Clusters and in Related Systems*, D. Reidel Publ. Co., Dordrecht, p. 145.
Dickens, R. J. and Rolland, A.: 1973, *Monthly Notices Roy. Astron. Soc.* **160**, 37.
Frolov, M. S.: 1970, in B. V. Kukarkin (ed.), *Pulsating Stars*, Nauka, Moscow, pp. 124, 263.
Goranskij, V. P.: 1973, in J. D. Fernie (ed..), *Variable Stars in Globular Clusters and in Related Systems*, D. Reidel Publ. Co., Dordrecht, p. 207.
Goranskij, V. P.: 1974, *Astron. Tsirk*, No. 832.
Gryzunova, T. I.: 1972, *Variable Stars*, Suppl. **1**, 253.
Hartwick, F. D. A.: 1968, *Astrophys. J.* **154**, 475.
Hoffmeister, C.: 1970, *Veränderliche Sterne*, Leipzig.
Iben, I.: 1971, *Publ. Astron. Soc. Pacific* **83**, 697.
Iben, I. and Rood, R. T.: 1970, *Astrophys. J.* **161**, 587.
Iwanowska, W.: 1953, *Torun Obs. Bull.*, No. 11.
Jones, D. H. P.: 1973, *Astrophys. J. Suppl.* **25**, 487.
Kholopov, P. N.: 1971, *Variable Stars* **18**, 115.
Kukarkin, B. V.: 1947, *Astron. J. U.S.S.R.* **24**, 269.
Kukarkin, B. V.: 1949, *Investigation of Structure and Development of Stellar Systems on Base of Variable Stars* (in Russian), Moscow.
Kukarkin, B. V.: 1974a, in A. A. Boyarchuk (ed.), *Phenomena of Instability and Stellar Evolution*, Nauka, Moscow.
Kukarkin, B. V.: 1974b, *The Catalogue of Globular Clusters of our Galaxy*, Moscow.
Kukarkin, B. V. and Kulikovsky, P. G.: 1951: *Variable Stars* **8**, 1.
Kukarkin, B. V. and Voroshilov, Yu. V.: 1971, *Astron. J. U.S.S.R.* **48**, 1087.
Kukarkin, B. V., Kholopov, P. N., Efremov, Yu. N., Kukarkina, N. P., Kurochkin, N. E., Medvedeva, G. I., Perova, N. B., Fedorovich, V. P., and Frolov, M. S.: 1969–1970, *General Catalogue of Variable Stars*, Vols. 1 and 2, Nauka, Moscow.
Kukarkin, B. V., Kholopov, P. N., Efremov, Yu. N., Kukarkina, N. P., Kurochkin, N. E., Medvedeva, G. I., Perova, N. B., Pskovsky, Yu. P., Fedorovich, V. P., and Frolov, M. S.: 1971, *First Supplement to the Third Ed. of the General Catalogue of Variable Stars*, Moscow.
Kurochkin, N. E.: 1961, *Variable Stars* **13**, 248.
Kurochkin, N. E.: 1962, *Variable Stars* **14**, 196.
Kwee, K. K.: 1967, *Bull. Astron. Inst. Neth.* Suppl. **2**, 97.
Kwee, K. K.: 1968, *Bull. Astron. Inst. Neth.* **19**, 260, 374.
Kwee, K. K. and Braun, L. D.: 1967, *Bull. Astron. Inst. Neth.* Suppl. **2**, 77.
Ledoux, P. and Walraven, Th.: 1958, in S. Flügge (ed.), *Handbuch der Physik* **51**, Springer, Berlin, p. 353.
Mandel, O. E.: 1971, *Variable Stars* **17**, 599.

Mengel, J. G.: 1973, in J. D. Fernie (ed.), *Variable Stars in Globular Clusters and in Related Systems*, D. Reidel Publ. Co., Dordrecht, p. 214.
Menzies, J.: 1974, *Monthly Notices Roy. Astron. Soc.* **168**, 177.
Mironov, A. V. and Samus', N. N.: 1974, *Variable Stars* **19**, 337.
Münch, G. and Terrazas, L. R.: 1946, *Astrophys. J.* **103**, 371.
Oosterhoff, P. Th.: 1939, *Observatory* **62**, 104.
Pavloskaya, E. D.: 1953, *Variable Stars* **9**, 349.
Peterson, C. J.: 1974, *Astrophys. J.* **190**, L17.
Preston, G. W.: 1959, *Astrophys. J.* **130**, 507.
Rastorgouev, A. S.: 1974, Thesis.
Roberts, M. and Sandage, A.: 1955, *Astron. J.* **60**, 185.
Rosino, L.: 1962, *Asiago Contr.* No. 132.
Rosino, L.: 1970, *Trans. IAU* **XIVA**; D. Reidel Publ. Co., Dordrecht, p. 292.
Rosino, L.: 1973, in J. D. Fernie (ed.), *Variable Stars in Globular Clusters and in Related Systems*, D. Reidel Publ. Co., Dordrecht, p. 51.
Sawyer Hogg, H.: 1973, *Publ. David Dunlap Obs.* **3**, No. 6.
Schwarzschild, M.: 1970, *Quart. J. Roy. Astron. Soc.* **11**, 12.
Schwarzschild, M. and Harm, R.: 1970, *Astrophys. J.* **160**, 341.
Strohmeier, W.: 1972, *Variable Stars*, Pergamon Press, Oxford.
Struve, O.: 1950, *Publ. Astron. Soc. Pacific* **62**, 217.
Swope, H.: 1968, *Astron. J. Suppl.* **73**, 204.
Tsessevich, V. P.: 1966, *The RR Lyrae Stars* (in Russian), Naukova Dumka, Kiev.
Tsessevich, V. P.: 1970, in B. V. Kukarkin (ed.), *Pulsating Stars*, (in Russian), Nauka, Moscow, p. 177.
Vasilyanovskaya, O. P. and Erleksova, G. E.: 1968, *Astron. Tsirk. U.S.S.R.*, No. 469.
Vasilyanovskaya, O. P., Erleksova, G. E., and Shakhovskaya, N. I.: 1966, *Bull. Tadjik Astrophys. Inst.*, No. 48.
Wallerstein, G.: 1970, *Astrophys. J.* **160**, 345.
Wehlau, A. and Potts, N.: 1972, *Info. Bull. Var. Stars*, No. 752.
Woolley, R. v. d. R.: 1966, *Observatory* **86**, 76.
Zinn, R. J.: 1974, *Bull. Am. Astron. Soc.* **6**, 203.

REMARKS

V. P. Tsessevich: Dr Kukarkin had no opportunity to describe the organizational side of the observing of RR Lyrae-type stars. Hence, I would like to discuss this.

Fifteen years ago, at the Moscow I.A.U.-meeting a resolution was adopted to organize systematic observations of RR Lyrae variables, the organization being in the hands of the Odessa Observatory. 200 objects were put on the programme. The results were to be sent to the Cracow Observatory and published in the *Annual Supplements* first by Dr Kordilewsky and now by Dr Kreiner. After several difficulties the catalogue and ephemeris are now in shape. The results are included in my monograph *The RR Lyrae stars*, which has been translated into English.

At present at Odessa, G. A. Lange, B. N. Firmanuk and V. Bezdenezny are regularly observing about 120 RR Lyrae stars, the ones with larger amplitudes visually, those with small amplitudes photoelectrically. Participation of more observers, including amateurs is desirable. The programme and the results should be communicated to us, so that the catalogue can be kept up to date. Observations in the southern hemisphere should be organized too.

Long series of photoelectric observations should be deposited in London and at Odessa according to the resolutions of Commission 27.

I. F. Alania: Information on various characteristics of RR Lyrae stars has considerably increased, but there is no success in the field of quantitative analysis of their atmospheres. It is desirable to extend Preston's pioneer investigation on the brighter stars of the type. It would enable us to obtain more accurate calibration of the relation between spectroscopic and photometric data and metal abundance. It is important to perform metal abundance determinations both at minimum and maximum light, since metal indices vary with different phases of the light curve.

There also exists a certain lag in the field of photometry of the continua of RR Lyrae stars. It is sufficient to say that in all the earlier papers the relation for transforming $B-V$ colour indices into effective temperature obtained by Oke *et al.* for a single star, SU Draconis, is used.

Remark by the editor: Recently, Van Albada and De Boer (*Astron. Astrophys.*, in press) obtained new Strömgren photometry of a few other RR Lyrae stars and derived physical parameters like surface gravity, effective temperature, radius and their variation during the whole cycle. In addition, a similar, but much extended programme by J. W. Pel using Walraven photometry is under way at Leiden Observatory.

L. Rosino: I should like to remark in connection with Prof. Kukarkin's report, that at the Asiago Astrophysical Observatory the following researches are being carried out:

(1) researches in the changes of periods of RR Lyrae stars;

(2) light curves in B and V of variables with $P>1^d$;

(3) searches for RR Lyrae stars far from the centers of globular clusters;

(4) further studies of distant clusters and Palomar clusters (=faint globular clusters discovered on Palomar Sky Survey plates, see, for instance, G. O. Abell, *Publ. Astron. Soc. Pacific* **67** (1957) 258).

DISCUSSION

B. V. Kukarkin: Changes in the periods of RR Lyrae variables are often masked by noise. This noise is much stronger for stars with a Blažko effect. It is necessary to carry out a mathematical analysis in order to see what kind of stochastic processes are concerned. Today, there exist only a few attempts in this direction. I draw your attention to a paper by T. I. Gryzunova (1972) on the changes of periods of RR Lyraes in NGC 5466. 17 variables were studied; the features of variability of their periods can be represented rather well by Poisson's law.

We must keep in mind that real evolutionary changes take place very slowly.

Another problem is to consider very carefully before beginning a major programme the wavelength band to be used. For instance the V band is not suitable for red stars.

Concerning membership of a cluster, proper motion may be a good criterion, but even this may not be sufficient, see Kadla's paper (1972). Radial velocities are a much more reliable criterion.

References

Gryzunova, T. I.: 1972, *Variable Stars*, *Suppl.* **1**, 253.
Kadla, Z. I: 1972, *Astron. Zh.* **49**, 661.

J. Kreiner (Cracow Obs) draws attention to the Cracow ephemeris, which can be obtained on request.

D. H. P. Jones: I should like to add that I have the index $(k-b)_2$ for a further thirty variables in addition to the variables in ω Cen and 47 Tuc reported at the Toronto Colloquium. At the moment I am working on the variables with periods between one and two days. About ten variables, selected mostly from the lists of Mandel and Tsessevich, are being compared with three in ω Cen and one in NGC 6752. It is planned to continue these observations, together with many others in globular clusters, with the Anglo-Australian telescope when it is commissioned.

D. H. P. Jones: In ω Cen where all the stars have the same metallicity, the stars with variable light curve are concentrated towards the gap in the histogram at $P\approx 0.43$ days. Clearly such stars have difficulty in deciding in which mode to pulsate.

Yu. S. Romanov: (1) Preston's metal-content parameter ΔS concerns only the difference in spectral types as derived from Ca^+ and H lines. Lines of other metals should also be included in the inspection of RR Lyrae spectra.

(2) Special attention should be given to stars with Blažko effect; viz., simultaneous photometric and spectroscopic (including radial velocity) observations are proposed. As an example, RZ Lyr and SW And are mentioned.

L. Plaut: Concerning the frequencies of the periods: These diagrams must be corrected for the discovery probability before a comparison, for instance, between the diagrams for the Galaxy (the field) and the various globular clusters can be made. The clusters are searched much more extensively than the field, which means that many more c-type stars have been found (relatively). Has this been taken into account in the histograms shown?

Can it be proven (statistically) that the frequency diagram for the galactic field cannot be made up by a combination of the two Oosterhoff groups?

B. V. Kukarkin: The correction mentioned is complicated. It has been applied to the various groups of light curves, RRab and RRc by many earlier authors, but we had no need of it. I think that the samples of known RR Lyrae stars in our Galaxy and in the globular clusters are quite comparable, since there exist both well and poorly studied clusters and both well and poorly studied areas in the sky.

The absence of a minimum in the galactic field histogram can only be explained by combining many distributions.

E. D. Pavlovskaya drew the attention to the publication in *Variable Stars* **18** (1972) 367, by Basharina, Pavlovskaya and Filippova.

P. Kunchev drew the attention to a long series of photometric and spectral observations of the Blažko-effect stars RZ Lyr and XZ Cyg.

D. S. Evans: Especially for stars with noticeable Blažko effect or other irregularities, it is essential to make photometric and spectroscopic observations as nearly simultaneously as possible.

E. H. Geyer: Prof. Kukarkin touched upon the intriguing problem of variability of stars bordering the RR Lyrae gap in the C-M diagram. In NGC 5139 (ω Cen) there are about a dozen stars known which fall in the blue part of the RR Lyrae gap in the C-M diagram of this cluster. I checked photoelectrically some of these stars for variability and found them constant within an accuracy of about $\pm 0\overset{m}{.}03$ in V. It does not seem plausible that all these stars are not cluster members.