PART I

GENERAL PROBLEMS OF VARIABLES IN POPULATION II SYSTEMS

VARIABLES IN GLOBULAR CLUSTERS, THE COMMON AND THE RARE

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The title of this talk is really just a different phrasing from one I have used at several IAU meetings on the subject of numbers and kinds of variables in globular clusters. To furnish this material, I have finished the *Third Catalogue of Variables in Globular Clusters*. Since many of you are coming to this Colloquium with new information, the Catalogue is in draft form with a request that corrections and additions be given me by October 2, after which the draft will go to the printer.

The *First Catalogue of Variables in Globular Clusters* was published at this observatory in 1939 and the Second Catalogue in 1955. In 1966 appeared the excellent *Catalogue of Variables South of Declination* −29° by Fourcade, Laborde and Albarracin, with splendid large prints of identification charts.

The globular clusters searched for variables now total 105, and the number of variables found has passed the two thousand mark, to 2057. These numbers compare with 72 clusters searched and 1421 variables found, listed in the Second Catalogue. In 1955 I was surprised when the most frequent number of variables per cluster examined turned out to be one! This summer I had another surprise from the new tabulations. In the clusters searched to date, the most frequent number of variables per cluster is – zero! Twelve of the clusters searched have no variables. And the three variables in NGC 6397 are all described as field stars, so if these are excluded that would make a 13th cluster with no variables. Of the clusters with no variables, 6 are the deep southern clusters recently searched by Fourcade and Laborde. Time will tell how much selection effect is involved here. Naturally the clusters searched now will mostly be the more distant or highly obscured.

There are now five clusters each of which has more than 100 variables. These are Messier 3 with 212, Omega Centauri with 175, IC 4499 with 129, Messier 15 with 111 and Messier 5 with 102. As the survey becomes more complete, those with large numbers of variable stars stand out as rather rare systems. It is fortunate that the rich ones were among the earliest investigated, now 80 years ago by Prof. S. I. Bailey of Harvard, otherwise the project of hunting for variables in globulars might not have had so much impetus.

Of course RR Lyrae stars greatly predominate among the variables discovered. The statement I made years ago that roughly 90 percent of the variables in globular clusters are RR Lyrae stars still seems to hold. Periods have now been determined for 1157 RR Lyrae type in 46 clusters, providing much material for statistical correlations. The distribution of frequency of periods is not markedly different from that in 1955. There is a strong preference for periods between 0.28 and 0.40 day, and 0.46 through 0.66 day. Nearly 95 percent of the RR Lyrae periods in globular clusters fall within

J. D. Fernie (ed.), Variable Stars in Globular Clusters and in Related Systems, 3–7.

those intervals, with 23 percent in the shorter and 71 percent in the longer interval. Further significance is obtained when the frequency is studied cluster by cluster and correlated with various known properties of the cluster, as for example the correlation of Oosterhoff's Groups I and II with metallicity. Ever since Dr Martin Schwarzschild put the cluster variables in their place, that is in their gap in Messier 3, the processes which involve RR Lyrae stars have become better understood all the time.

At the long end of the RR Lyrae periods, an interesting anomaly is the number with longer periods in Omega Centauri. That cluster has 13 with periods longer than 0.75 days, more than twice as many as in all other globular clusters combined. And at the short end, two dwarf Cepheids have been detected, but probably neither is a cluster member. One in Omega Centauri has a period of 0.06 day and one in Messier 56 has 0.07 day.

Period changes are an important aspect of these stars, and are indicated in the catalogue merely by a + or − sign. Values of Beta for the same star by different investigators sometimes differ widely. Furthermore, Dr B. V. Kukarkin considers Beta to be a rather illusory quantity, and thinks that the best way of understanding the behaviour of the star is by O − C diagrams for different epochs. Period changes as well as the important aspect of colours will be discussed in later papers at this colloquium.

There are now 169 variables indicated not to be RR Lyrae stars in 44 clusters. I have arbitrarily divided them by period length. In the 1–30 day category, total 29, are the W Virginis stars and a few Cepheids with periods under a week. The 31–99 day category, total 23, includes a few RV Tauri stars, but is mainly made up of semiregular or cyclical variables. If no numerical value of a cycle is given, the star is assigned to the less definite irregular or semiregular category, which totals 27. In the range from 100 to 220 days, total 23, is found the type of long period variables which Dr Feast and his colleagues have been so diligent in proving to be actual cluster members. By contrast none of the 12 variables with periods over 220 days has been shown to be a cluster member and most of them have been proven field stars. Feast's limit of 220 days for the period of a globular cluster member still holds, but will it last through this colloquium? Clusters that have variables usually have both the RR Lyrae and slow types. It is rare for a cluster to have only one or the other. The cluster which really stands out with its richness in non-RR Lyrae variables is Omega Centauri. It has 17 in all, but not all of them are members. There are 7, all members, in the 1 to 30 day category, 5 in the 31 to 99 day, some of which are field, one 149 day, one field star at 235 days and 3 eclipsing stars, at least one of which is a member. Variable No. 1, the brightest variable in the cluster which has been considered for years to be RV Tauri type is now assigned a 29-day period with intermediate RV Tauri characteristics, by D. H. P. Jones. Great credit is due to the Herstmonceux observers for their massive pieces of valuable work on this cluster.

The recent detection of more irregular or semiregular variables in clusters constitutes a very important addition to our understanding of the stellar content of these. To a great extent this has come about through the marked increase in colour magnitude diagrams and colours available for individual stars. No one, I think, is going to try to fit an RR Lyrae period to a star near the tip of the red giant branch in a cluster, but in the past, when we did not know the star belonged there, we might have spent hours trying to do it. The multi-color work of O. J. Eggen has shown that many of the irregular variables in clusters lie in just such a location, and he goes so far as to suspect that all stars in clusters with $B-V$ greater than $+1.6$ will prove to be red irregular variables.

Some stars announced as variable by early workers have since been shown to be non-variable. But in recent years there has been a surprising twist to this, namely that three such stars have been shown to be really variable! These are in Messier 3, Nos. 8 and 15 by Kholopov, and No. 138 by Russev.

There are only about a dozen-and-a-half variables in globular clusters which do not fall into the foregoing categories of pulsating stars. Eclipsing systems represent about two thirds of these. One appears to be a member of NGC 3201 and at least one (No. 78) out of the three in Omega Centauri is a member. Sistero has noted that Var. 78 is the brightest known eclipsing binary of extreme Population II. One Algol type eclipser is in NGC 6838, and my tentative period is given for the first time in the Third Catalogue as 3.9 days. Perhaps the photometric study of this cluster by Arp and Hartwick will help determine whether or not it is a member. It is possible that our information on binary stars in globular clusters will increase substantially in the years ahead. The work of my colleague, Dr Christine Coutts, has shown that the binary character of an RR Lyrae variable can have a measurable effect on its observed period fluctuations.

Explosive variables account for half-a-dozen in globular clusters. Three U Gem stars have been observed, one near Messier 5, one near NGC 6712 and the other near Messier 30. They are all very faint, and little information is available on them. Perhaps they are all field stars. Three novae have been found, at least two of which seem to be members. The first was discovered visually in 1860 by Auwers in M80, and rose to just under naked eye visibility, magnitude 6.5 or so, changing the whole appearance of that compact little cluster. The second was found in 1949 by Mrs Margaret Mayall on spectrum plates of NGC 6553 taken at the Boyden Station of the Harvard Observatory in 1943. These plates cannot now be located for checking. The third, in Messier 14 was found by my collaborator Dr Amelia Wehlau in 1964 while working on plates I took with the 74-in. David Dunlap reflector in 1938. A series of 8 plates on nights in one week of June that year shows the star near 16th magnitude on all of them. It has never been found on any other plates of this or other observatories. It is very close to the centre of the cluster and there is no reason to think it is not an actual member. Most of the hunting for variables in globular clusters has not been of the sort that would detect novae. It was really good luck that those in NGC 6553 and M14 were found. Systematic novae search programs with plates taken bi-weekly over years might yield many more novae.

Now I would like to make a few remarks about the Canadian observational program which is actually the force behind these catalogues, and some previously unpublished material from it is included in the Third. My own work on globular clusters began in

1926 as a graduate student at the Harvard Observatory under Dr Harlow Shapley, and two people here today, Mrs Margaret Mayall and Miss Henrietta Swope were there then as graduate students also. In 1931 my husband Dr Frank Hogg was appointed to the staff of the Dominion Astrophysical Observatory, Victoria, B.C. In September, 1931 I began the cluster program there with the help of the Director, Dr J. S. Plaskett, and my husband, using the 72-in. reflector, at that time the second largest telescope in the world. I want to emphasize the extensive co-operation of many persons in this program for more than forty years. In 1935 my husband and I came to the David Dunlap Observatory and the 74-in. went into operation in May that year, at that time supplanting the DAO 72-in. as the second largest telescope. The program on variables in globular clusters has continued here ever since.

Great co-operation has come from the Observatory Directors, of whom the last two, Dr John F. Heard and Dr Donald A. MacRae are present today. National Research Council of Canada has given generous support to the program. Throughout all these years Gerry Longworth has kept the big telescope in top condition, and Frank Hawker and Anson Moorhouse have aided the program. My colleague, the late Professor Ruth Northcott gave valuable help, particularly during the hard war years.

Other, smaller telescopes have been used to supplement the 74-in. program. In 1939 the Director of the Steward Observatory of the University of Arizona, Dr E. F. Carpenter, gave me six weeks of time on the 36-in. there. Then the 19-in. built by Dr R. K. Young here has been used for many summers with student assistance. And the last five summers the new 16-in. atop this building, in the Burton Tower, has continued the program, run by Peter Chen, Kayll Lake, Rick Salmon and Chris Smith. The past year the new 24-in. of the University of Toronto has gone into operation on Las Campanas, Chile and superb cluster plates are coming back from it. Earlier, Dr Christine Coutts had obtained many plates for the program with the Michigan Schmidt on Cerro Tololo. As a doctoral student here Christine Coutts studied Messier 5, worked in Italy for a year under Dr Rosino, and is now continuing the program, specializing in period changes. Almost ten years ago Dr Amelia Wehlau of the University of Western Ontario began working on our plates, and now is acquiring her own with the new 48-in. at that University.

The catalogue has been completed with help from many astronomers who have sent in data, especially Dr B. V. Kukarkin, and from two librarians, Mrs Jean Lehmann and Mrs Sheila Smolkin, from our secretary Mrs Jennie Fabian and from my daughter Mrs Sally MacDonald who tabulated data.

The tables, figure and references accompanying this article will be included with the Third Catalogue, as *Publications of the David Dunlap Observatory* **3**, No. 6.

DISCUSSION

Menzies: Have you considered extending your Catalogue to cover Magellanic Cloud globular clusters?

Hogg: Yes, but it has been difficult enough to complete this third Catalogue without including any extra material. Perhaps later.

Feast: Is it possible to say in how many clusters the search for RR Lyrae stars has been exhaustive (or essentially exhaustive)?

Hogg: It's very difficult to say. In Messier 10 which Bailey had hunted carefully, I was pleased to find two variables which he had missed. And then a few years later Dr Arp found an important variable which I had missed.

Dickens: Most variables are discoved by 'blinking' of plate pairs, which must lead to incompleteness in the discovery of small amplitude variables such as *c*-types, particularly in crowded areas.

Hogg: Yes, there is a selection effect working against the discovery of the small range *c*-type variables.

Wesselink: The absolute magnitudes of flare stars are so much fainter than those of RR Lyrae's that they are missed on plates taken for RR Lyrae's only, which accounts for the absence of known flare stars.

Buscombe: Real-time searches with image orthicon tubes (similar to the successful identification of supernovae in distant galaxies at Corralitos) could be productive for variables in globular clusters if attempted on large telescopes.