PART III

SLOW VARIABLES IN POPULATION II SYSTEMS

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OBSERVATIONAL ASPECTS OF SLOW VARIABLES IN GLOBULAR CLUSTERS

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Abstract. There are up to 14 known Mira variables in seven globular clusters, though several have not yet been confirmed as radial velocity members. The periods of only 5 are known, all near 200 days. The clusters seem to form a compact group of relatively metal rich clusters. In 3 or 4 cases spectroscopy shows that the giant branches of these clusters penetrate into the M types. The Mira-containing clusters also contain red variables of shorter period and smaller amplitude which are generally also M type stars. Stars apparently evolve to the red of the giant tip as variables of increasing amplitude and period. Effects of TiO blanketing on the $(B-V)$ colours may be anticipated in these clusters.

Besides variables at the red giant tip the metal poor globular cluster ω Cen contains variables with strong TiO bands. Photometry, including recent J, H, K, L photometry by Glass shows that these stars are very cool objects. They indicate an extension of the giant branch considerably cooler than previously considered for metal poor clusters.

V1, NGC 121 in the Small Magellanic Cloud has a spectrum indicative of an SRd variable. It is not yet clear whether galactic stars similar to this star exist or not.

1. Introduction

The title of this review covers, in effect, all kinds of variables except RR Lyrae stars. However in order to give some coherence to the paper, the discussion will be almost entirely limited to the red giant variables; that is to variables in the general region of the tip of the red giant branch in the HR diagram. These stars are of considerable importance in helping to understand what is going on at, and beyond, the red giant tip. As yet there is rather little detailed theoretical work on these stars, but with the increasing amount of observational work being carried out on them we may hope that more theorists will be tempted into this field.

2. Mira Variables in Clusters

Let us first consider the membership of Mira variables in clusters. For our purposes we define Mira variables as red giants with long periods (generally greater than 100 days), large amplitudes (Δm greater than about $2^{m}.5$) and Me spectra (that is spectra showing TiO bands and emission lines, generally Balmer lines, at least at some phases). It is quite instructive as a start to look at a list (Table I) of Mira variables which lie in the direction of globular clusters and which have been shown to be non-members of the clusters. Generally, of course, membership is decided on the basis of radial velocity work, which is usually unambiguous since the clusters and, to a lesser extent, the Mira variables have large peculiar motions and chance agreement of velocity is unlikely. It is worth noticing that the Mira variables in Table I scatter over quite a large range in periods (177–334 days). When we look at Miras that are members of clusters we find that they cover a much more restricted range of periods.

J. D. Fernie (ed.), Variable Stars in Globular Clusters and in Related Systems, 131–144.

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TABLE I

Field Miras in the direction of globular clusters

Cluster		Variable	Period (days)	ΔV (km s^{-1})	Reference
NGC 6656	M22	V14	200	201	*Astrophys. J.* **110**, 105.
4590	M68	FI Hya	324	214	*Publ. Astron. Soc. Pacific* **59**, 143.
4833		RZ Mus	334	252	*Observatory* **86**, 120.
6397		V1	315	30	*Observatory* **86**, 120.
5139	ω Cen	V2	242	281	*Observatory* **85**, 16.
6171		V720 Oph	332	> 100	Dickens (private communication).
6093	M80	S Sco	177	67	
6093	M80	R Sco	222	19[a]	

ΔV is the difference between the cluster radial velocity and the radial velocity of the variable.
[a] This value of ΔV is not large enough to rule out membership but the star is far out from the cluster making membership unlikely. If it were a member it would be an extremely bright object ($M_v \sim -5.5$ at mean maximum).

TABLE II

Mira variables in globular clusters

Cluster	Variable	Period (days)	M_v	Spectrum	Membership
47 Tuc	V1	212	−3.2	Me	+
	V2	203	−3.3	Me	+
	V3	192	−3.2	Me	+
NGC 6712	CH Sct	191	−3.6	Me	+
NGC 6637	V4	196		Me	+
	V10	?		Me	+
NGC 6388	V1	?		Me	+
	V4	?		Me	
	probably one other Mira				
NGC 6356	V3	?		Me	+
	probably two other Miras				
NGC 5927	Osborne	?		Me	
NGC 6553	V4	?		Me	

+ = radial velocity member

Table II summarizes the present position regarding Mira members of clusters. The three best known stars in this Table are the Miras in 47 Tuc, all with periods near 200 days. Following the work on the 47 Tuc variables (Feast and Thackeray, 1960), one star in NGC 6712 and two NGC 6637 were shown to have typical Mira spectra and to be radial velocity members of these clusters (Feast, 1967; Catchpole *et al.*, 1970). Of these three stars only two have had periods determined as yet. Both these periods are close to those of the 47 Tuc variables. Osborne (1968) located a slow variable near the centre of NGC 5927 and spectra obtained this season show it to be a typical Me Mira variable (unless otherwise stated the spectroscopic work mentioned in this paper was carried out at 140 Å mm^{-1} with the grating spectrograph and Carnegie Image Tube at the Cassegrain focus of the 74-in, (1.88 m) Radcliffe reflector). The period of this star is not yet known.

The discovery of Mira variables in clusters has recently been much accelerated by Lloyd Evans' work on *V* and *I* photography. He will be describing this work in collaboration with Menzies at this meeting, but I have taken the liberty of including some of his discoveries in Table II. The table lists several possible Miras he has selected in NGC 6356, 6388 and 6553 (in the last case the variable is one originally found by Thackeray (1955)). Table II also shows that where I have checked up on these stars spectroscopically they are found to have typical Me spectra. We obviously badly need periods for all these stars. The five known periods are close to 200 days. Dr Lloyd Evans' work suggests that the period of NGC 6553 V4 may be significantly longer than this – possibly 270 days.

One reason why a knowledge of the periods is of great interest is that the kinematics of Mira variables in the general field indicates a fairly good correlation of period and kinematic properties. Thus, in view of the small range of the known periods (191–212 days) we may inquire whether the clusters themselves form a rather tight group of similar objects.

TABLE III

Data on clusters containing Miras

Cluster	Morgan class	Deutsch/Kinman class	Kinman/Morgan CH/Hγ	H	Fe	ΔV	HB
47 Tuc		A	G3	G3	G3	2.15	Red
NGC 6712	V		G5			2.2	Red
NGC 6637	VII		G5	G8:	G2		
NGC 6388			G3	G3	G3		
NGC 6356	VI		G5	G2	G5	2.15	Red
NGC 5927			G2				
NGC 6553	VIII						

ΔV measures the height of the giant branch.
HB indicates which side of the RR Lyrae gap the horizontal branch is strongly populated.

Data on the clusters is summarized in Table III. Taking together the evidence of the colour magnitude diagrams (height of giant branch measured by ΔV, population of the horizontal branch (blue or red side)), Deutsch-Kinman classes, Morgan classes etc. it is clear that we are dealing with a group of metal rich globular clusters. These results are of course consistent with the kinematics of 200 day Miras in the general field, which indicate a very old population but not one as extreme as that of the very metal poor halo objects (Feast, 1963).

When 47 Tuc was first investigated spectroscopically one of the things that seemed remarkable was that the reddest non-variable stars were of spectral type M (up to about M2 at the latest) (Feast and Thackeray, 1960). It had not then seemed likely that globular cluster giants would be sufficiently metal rich and/or cool to show M type spectra. Over the years the presence of M type non-variable stars has generally been regarded as a unique property of 47 Tuc, though Stephenson (1961) found from objective prism work that there were some M type stars (M0 to M3) in the region of M17 which could be members of that metal rich cluster. M17 is not known to contain Mira variables and therefore does not appear in Table II. However there are a number of variables in the region including the long period irregular variable Z Sge which has a type of M4 according to Stephenson and $M_v \sim -1$ (Arp and Hartwick, 1971).

Are the other clusters in Table III sufficiently similar to 47 Tuc to show TiO bands in their non-variable red giants? A number of spectra have been taken to test this hypothesis. Table IV gives data on two red giants in NGC 6356. The photometry is

TABLE IV

Cluster	Star	V	$(B-V)$	$(B-V)_0$	Spectral type
(a) Non variable red giants in metal rich clusters					
NGC 6356	5	15.35	2.05	1.55	M0–1
	46	15.35	2.22	1.72	M2
NGC 6637 (M 69)	IV-27 (inner)				M0 or 1
	III-42 (outer)				probably not M type
NGC 6553	TLE 24 (? variable)				M4
(b) Small amplitude red giants, in some metal rich clusters					
NGC 5927	LF 4				M3
NGC 6637 (M 69)	V1				M2
	V3				probably not M type

from Sandage and Wallerstein (1960). Radial velocities of these stars are not known, but both lie on a well defined giant branch and are thus rather unlikely to be field stars. Star 46 is the reddest star in NGC 6356 measured by Sandage and Wallerstein and has the same spectral type as the latest red giants in 47 Tuc. Within the uncertainty introduced by the reddening correction to the NGC 6356 stars ($\pm 0\overset{m}{.}1$) the intrinsic colours of these M stars lie in the range of the 47 Tuc M giants (1.5–1.6). On this evidence NGC 6356 is quite similar to 47 Tuc.

In NGC 6637 (M69) Lloyd Evans and Menzies (1971) have shown that the photometry of Hartwick and Sandage (1968) needs substantial revision. However this photometry does at least allow us to pick out the stars at the red giant tip. The reddest giant not known to be variable (Hartwick and Sandage IV-27, inner zone) is of type M0 or M1. The next reddest giant (III-42 outer zone) does not show TiO bands with certainty (cf. Table IV). Evidently the non-variable giant branch of this cluster also penetrates into the early M types.

NGC 6553 is of special interest since its Mira may be of longer period than the others. It is certainly a metal rich cluster but otherwise rather little is known about it. However, Lloyd Evans finds a considerable number of stars with large $(V-I)$ colours in the region of the cluster. One of these stars (star 24 in Lloyd Evans' system) which may perhaps be a small range variable is of spectral type M4. This is definitely later than the latest non-variable red giants in 47 Tuc and marginally later than even the semiregular red variables in 47 Tuc. This is perhaps a tantalizing hint that longer periods are associated with greater metal richness and/or cooler giant tips.

It has long been recognized that the presence of TiO in the red giant variables in 47 Tuc produces a spurious blueing of $(B-V)$. Evidently one must anticipate the possibility of such effects in all the Mira-containing clusters. For these clusters, therefore, there is good reason to abandon $(B-V)$ and use colours in the infrared. Lloyd Evans and Menzies will be talking about their photographic work. Eggen (1972) has obtained (R, I) photometry which shows the important part this can play in globular cluster work. Wing will later be discussing results obtained with his narrow band system.

3. Small Amplitude Red Variables in Metal Rich Globular Clusters

Besides the three 200^d Mira variables, 47 Tuc contains five other red variables. The data on these stars are shown in Table V. Arp *et al.* (1963) noted that these eight variables seemed to divide into three groups with periods near 50^d, 150^d and 200^d and with amplitude and absolute magnitude at maximum increasing with period. It is not clear whether these groups are just a chance effect due to the small numbers of variables involved, or whether they are of significance for pulsation theory. In any case the spectral type becomes later with increasing period so that there are reasonable grounds for believing that stars evolve off the giant tip, moving to lower temperatures, with increasing amplitudes and periods. This conclusion is nicely illustrated by recent

TABLE V

Variable	Period	ΔV	V_{max}	M_v (max)	Max. type
47 Tuc red variables					
5	45^d	0.4	11.5	−2.0	M2
6	47	0.6	11.3	−2.2	
7	58	0.5	11.4	−2.1	M2
4	165	1.8	10.9	−2.6	
8	155	1.7	10.9	−2.6	M2–3 (e)
1	212	4.4	10.2	−3.2	M2–3 (e)
2	203	3.7+	10.2	−3.3	M2–3 (e)
3	192	4.3	10.3	−3.2	M2–3 (e)
ω Cen TiO variables					
RGO 320	?	0.5	12.4	−1.7	M2
V17	60	0.8	12.7	−1.4	M3–4
V6	100–120	1.2	12.2	−1.8	M4–5 (e)
V42	149	>3.3	11.2	−2.9	M2 (e)

	E_{B-V}	$V_0 - M_V$
47 Tuc	+0.03	13.4
ω Cen	+0.11	13.7

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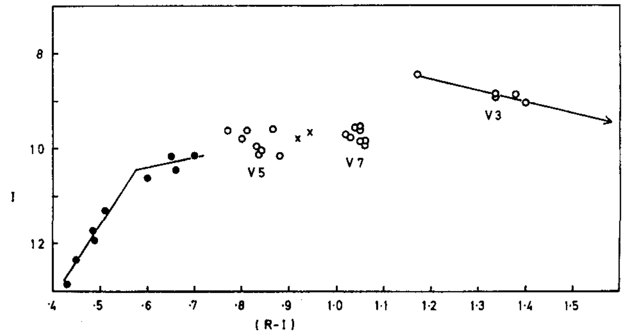

Fig. 1. $I,(R-I)$ diagram for 47 Tuc using data from Eggen (1972). Filled circles non-variables; crosses two small amplitude variables. Groups of open circles indicate the 45 day variable V5, the 58 day variable V7 and the 192 day Mira V3. In the case of V3 only points in the brighter part of the cycle are shown, other points lie outside the figure in the direction of the arrow.

(R, I) photometry by Eggen (1972) which is plotted in Figure 1. Included are two additional small amplitude variables noted by Eggen (one of them originally found by Arp *et al.* (1963)). Note how the variables lie to the red of the red giant tip with the Mira reddest of all. Comparison of this plot with a V, $(B-V)$ plot (Arp *et al.*, 1963, Figure 10) shows the dramatic effect of TiO absorption on $(B-V)$. In this latter plot the three 50 day variables lie near the red giant tip but the 150^d and 200^d variables, which are cooler, are displaced to the blue. Even R and I may be somewhat affected by TiO and for some purposes there may be good reason to go further into the infrared. Glass has recently carried out some Johnson J, H, K, L photometry (1.2–3.4 μ) in Pretoria which also clearly shows that the variables in 47 Tuc are cooler than the stars at the red giant tip.

All the other clusters with Mira variables also contain red variables with smaller amplitudes which could well be similar to the small amplitude variables in 47 Tuc. These stars promise to give useful information on evolution off the red giant tip, but so far the data is too fragmentary for a proper discussion. After 47 Tuc the most extensive discussion of non-Mira red variables in metal rich clusters is that on NGC 6712 by Rosino (1966) and by Sandage *et al.* (1966). Besides the Mira variable in this cluster, periods and light curves are known for 4 or 5 other red variables. The results resemble the 47 Tuc work at least to the extent that there are some SR variables of moderate amplitudes and periods of $\sim$100 days. However, a meaningful discussion will hardly be possible until spectra or multicolour photometry have been obtained. Spectra are necessary to establish radial velocity membership, since the cluster is in a relatively rich field, and to help classify the variables. For example V2 has in the past been considered by one writer as an RV Tauri star and by another as an SRd variable, whilst it could well be an M type SR variable.

In the case of NGC 5927, Fourcade, Laborde and Albarracin (1966) have found several variables without determining periods or amplitudes. Lloyd Evans' work indicates that some of these have large $V-I$ colours and small amplitudes and may well be similar to the 47 Tuc SR's. In fact the spectrum of one of them (LF4) is of type ~M3, marginally later than the 47 Tuc SR's.

Another cluster containing Miras, NGC 6637 (M69) also has several small amplitude variables. One of these (V1) has a spectral type of ~M2. Again similar to the 47 Tuc SR's. The case of the small amplitude variables V3 in this cluster is interesting. It lies to the blue of the red giant tip in the V, $(B-V)$ diagram, and Lloyd Evans and Menzies (1971) called attention to its position above the giant branch in a pseudo I, $(V-I)$ diagram. TiO bands cannot be seen with certainty in recent spectra of this star. If it is a cluster member it is likely to be similar to several variables in other clusters which have been shown by Eggen (1972) to lie in the region of the giant tip but somewhat to the blue of the tip. Possibly these stars lie on loops in their evolutionary tracks extending from the giant tip to higher temperatures.

The discussion so far may be summarized as follows:

(1) There are a number of clusters containing Mira variables.

(2) The periods where known are near 200 days.

(3) These clusters are all metal rich.

(4) Where tests have been made it is found that the non-variable red giant branch penetrates into the M type region in these clusters.

(5) These clusters generally also contain red variables of shorter period, and smaller amplitude than the Miras. These variables are also of type M, but somewhat earlier than the Miras. Stars apparently evolve to the red of the giant tip as variables of increasing amplitude and period.

(6) In all these clusters TiO blanketing is likely to confuse the interpretation of the V, $(B-V)$ diagram.

4. Red Variables in ω Cen

Turning now to metal poor clusters, let us discuss work on ω Cen in some detail. There are about a dozen semiregular and irregular giant variables in ω Cen. Most of these were included in Martin's (1938) extensive early discussion. In the 1971 season Lloyd Evans extended his V, I work to ω Cen, and Dickens and I obtained spectra of variables that seemed interesting in this survey. I want to summarize this work (Dickens *et al.*, 1972) as updated by further spectroscopic work this year. Briefly the main feature of the V, I work is that the red variables divide into two groups, one with $(V-I)$ values corresponding roughly to the tip of the giant branch, and one with much redder $(V-I)$ values. These redder stars are found spectroscopically to show TiO bands. Radial velocities have been obtained for many of the stars discussed. This is essential, at least in the case of the TiO variables, since we find both members and non-members in this group. M type non-members are not too much of a surprise since ω Cen is in a relatively rich field and covers a large area*.

Figure 2 shows the $I, (V-I)$ diagram for ω Cen. The giant branch is shown as dots from Brooke's (1969) work. Crosses are mean positions of non-TiO variables.

* RGO 4789, found variable by Dickens *et al.* (1972), has recently been found to be a radial velocity non-member.

These are quite small amplitude objects ($\Delta V \sim 0.5$ or less). The periods are in the range 70 to 124 days. It will be seen that these variables cluster around the giant tip. V164, a radial velocity member, falls below the red giant tip. It may or may not be significant that its period is ~37 days, shorter than any of the others. V167 falls well down the giant branch. However it was not found variable in our work and we do

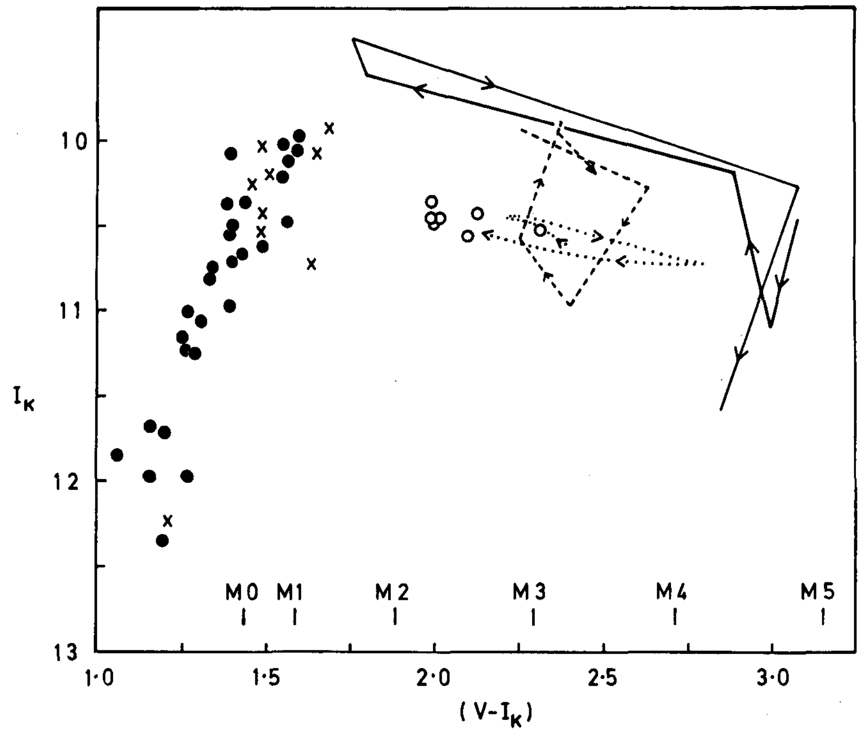

Fig. 2. I, $(V-I)$ diagram for ω Cen from Dickens *et al.* (1972) with the TiO variable RGO 320 (open circles) added. Filled circles are non-variable stars. Crosses are non-TiO variable (the faintest of these is V167 and the next faintest V164). The other TiO variables are V42 (full line), V6 (dashed line) and V17 (dash-dotted line). The non-variables are mostly from Brooke (1969).

not yet know if it is a member or not. These semiregular variables lying near the red giant tip and with spectra similar to red giants at the tip, presumably indicate the onset of instability at this point. They are presumably equivalent to the M type semi-regular variables of about the same period and amplitude in 47 Tuc, though occurring at a somewhat higher temperature (judging from Eggen's R, I measures and Glass' J, H, K, L results). Variables of this kind appear to be present in a number of metal-poor globular clusters.

The four variables whose paths in the I, $(V-I)$ diagram of Figure 2 are shown in detail are all radial velocity members of the cluster. There can be little doubt about

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this since the cluster has a high radial velocity*. Some data on these four variables are given in Table V and below. (a) V42 is affected by a close companion near minima. The star is generally classified as an SRd variable. It not known whether it moves out of the M types at maximum, but it shows TiO quite close to maximum. (b) V6 might be called a Mira except for its small amplitude. (c) RGO 320 was discovered to be variable by Lloyd Evans. (d) V17 was observed spectroscopically at monthly intervals in June, July, August 1971 and April, May, June, July and August 1972. The type from the TiO bands was always near M3 or M4. This coupled with the small amplitude and large $(V-I)$ values suggests that V17 and probably also V6 and RGO 320 always remain in the M types. It is obviously difficult to fix a precise mean point for these stars in the HR diagram. But even if we were to omit V42 from consideration because of its large amplitude, we would still find that in order to include the other TiO variables the giant branch would have to extend well to the red of the giant tip in $(V-I)$, and almost certainly also to bend down in I.

The most obvious, and most likely, interpretation of these results is that the evolutionary tracks extend to considerably cooler temperatures than we have been accustomed to think of for metal poor clusters. Can we rule out the possibility that these stars have temperatures similar to the non-TiO red variables, and that the strong TiO bands indicate abundance anomalies of an unsuspected kind? The large $(V-I)$ colours are probably no clear cut evidence against this since these colours are strongly affected by TiO blanketing. There are, however, at least two reasons for rejecting this hypothesis.

(1) The V, $(B-V)$ diagram was discussed by Dickens *et al.* (1972). Here again the non-TiO variables cluster around the red giant tip. The TiO variables have similar $(B-V)$ colours but lie below them. For the M stars the effects of TiO blanketing are marked. Making approximate blanketing corrections to V and $(B-V)$ (cf. Smak, 1966) it is found that the TiO variables move up to about the same V as the non-TiO variables and out to $(B-V) \sim 2.0$. This certainly suggests that the presence of TiO is a real indicator of low temperature.

(2) Glass (to be published) has obtained J, H, K, L photometry of a number of stars at the red giant tip in ω Cen, as well as some non-TiO variables and the TiO variables V17 and V6. A J, $(J-K)$ plot shows that the TiO variables have much larger $(J-K)$ values, indicating them to be much cooler than the other stars. After correction for a small amount of interstellar reddening, the $(J-K)$ colours of V17 and V6 agree with their TiO types (using the calibration of $(J-K)$ with spectral type given by Lee (1970)). Thus either these stars have compositions similar to ordinary field M giants, which is a little surprising for stars in a metal-poor globular cluster, or else the $(J-K)$, TiO-type relation is insensitive to metal abundance.

It is interesting to compare the TiO variables in ω Cen with those in 47 Tuc. The most conspicuous difference is that whilst the TiO variables in ω Cen lie below the giant

* Figure 2 contains an extra TiO variable compared with Figure 2 of Dickens *et al.* (1972). This is RGO 320 noted in that paper as a small amplitude variable and now found to be a radial velocity member (radial velocity $+226$ km s^{-1} from a 50Å mm^{-1} Carnegie Image Tube Spectrum).

branch in the V, $(B-V)$ diagram, the 47 Tuc variables lie on or slightly above the giant branch at mean light. This is presumably due either to different shapes to the giant branches in the two clusters and/or to TiO blanketing being different in the two clusters at the same temperature.

Table V compares the variables in 47 Tuc and ω Cen. The 160 day variables in 47 Tuc have $M_v = -2.6$ at maximum, whilst V42 ω Cen has M_v (maximum) $= -2.9$, but since this star has a much bigger amplitude it is fainter at mean light than the 47 Tuc stars. The 50 day variables in 47 Tuc have $M_v = -2.1$ at maximum. V17 with a similar period and amplitude has $M_v = -1.4$ at maximum and a later spectral type. RGO 320 ($M_v = -1.7$ at maximum) is also fainter than the 47 Tuc variables. These differences could be reduced or possibly eliminated by increasing the modulus of ω Cen by $\sim 0\overset{m}{.}5$. This is perhaps not out of the question. If there are real differences in absolute magnitude and other properties between the TiO variables in 47 Tuc and ω Cen, then one is faced with the unpleasant prospect that both 47 Tuc-type and ω Cen-type M variables may be present in the general field, and that these cannot be readily distinguished from one another on the basis of photometry or low dispersion spectroscopy.

5. The SRd Variables

In the general field there are about 15 to 20 rather similar stars which are generally grouped together under the name SRd variables. They have peculiar spectra, probably indicative of metal deficiency. They are generally classified Fp, Gp or Kp and usually they show TiO bands towards minimum. One of their chief characteristics is the presence of strong hydrogen emission lines near maximum. Generally their periods are in the range 75 to 120 days and their amplitudes between 1 and 4 mag. Their radial velocities show them to belong to a halo-type population, and it has been proposed that they form an extension of the main Mira variable sequence to periods shorter than 200 days into the halo population (Feast, 1965; Preston, 1967). Obviously as such we may well expect to find them in globular clusters. Table VI shows several variables in globular clusters which are probably SRd variables on the basis of Joy's (1949) spectroscopic work. They show hydrogen emission and in at least one case TiO bands near minimum. It may be of significance that their amplitudes are low compared with field SRd's, though there is one in the field with an amplitude less than 1^m (UW

TABLE VI

SRd variables (Joy)

NGC	M	Variable	Period	Amplitude	Spectrum	Morgan class	ΔV
6656	22	5	?	0.8	G0–G6 (e)		
6656	22	8	67 ±	0.7	G2–G5 (e)	II	2.5
5272	3	95	103	0.7	G4–M4 (e)	II	2.64

ΔV = Height of giant branch.

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Lib $\Delta m \sim 0.7$). Some of the other variables observed by Joy could be SRd's though they did not have hydrogen emission when he observed them. However these latter stars may also be similar to the non-TiO variables in ω Cen, which do not classify as SRd's as their amplitudes are too small and they do not have hydrogen emission.

As mentioned in the last section, V42 ω Cen seems best classed with the SRd's. Its period is, however, long compared with typical SRd's in the field or others known in globular clusters. V42 ω Cen seems to bridge the gap between 100 day SRd's and 200 day Miras. We know that the kinematics of the field stars in the main Mira-SRd sequence are correlated with period and this presumably indicates some correlation of metal abundance with period. We have, however, little idea of just how close this correlation is, though we have seen that Miras with periods close to 200 days occur in a group of rather similar metal-rich clusters. V42 ω Cen provides an interesting problem in this connection. Table VII compares this variable with the bright Mira variable

TABLE VII

Comparison of V42 ω Cen and S car

Star	Period	Amplitude	Spectrum	Radial velocity (km s^{-1})
V 42	149.4	>3.3	$\sim$ M2e	+261
S Car	149.5	mean 2.9 mean 5.4	K7e–M4e	+289

S Car. The periods and amplitudes are very similar. Like ω Cen, S Car is a high velocity object, which presumably indicates membership of the halo population. Hain (1969) has made a detailed study of S Car. Despite the very high velocity, the metal deficiency is only moderate ($\sim 1/10$ solar). Dickens (this conference) has summarized the present position regarding abundances in ω Cen. Whilst the ultraviolet excesses of the giants indicate metal abundances of $\sim 1/50$ solar, a preliminary spectroscopic analysis of Fehrenbach's bright member suggests an abundance of $\sim 1/15$ solar. Is the value derived for Fehrenbach's star the true value for the cluster as a whole? If not, could it at least apply to V42? It should not be impossible to answer these questions and this would greatly advance our knowledge of red variables in globular clusters.

Red variables are likely to become of increasing importance in attempts to understand the Magellanic Clouds. I want now in conclusion to discuss the brightest red variable in the SMC globular cluster NGC 121 in an attempt to see how it is related to the red variables we find in globular clusters in the Galaxy. The variables in NGC 121 were first investigated by Thackeray (1958) and later by Tifft (1963). The photometric properties of the brightest variable V1 are given in Table VIII. A recent spectrum taken near maximum light shows a fairly smooth continuum with no sign of TiO bands but with strong hydrogen lines in emission. The star thus almost certainly classes as an SRd variable. In Table VIII it is compared with two other SRd's, V42 ω

TABLE VIII

Comparison of three SRd variables

Cluster	Variable	Period (days)	Amplitude ΔV	$B-V$		Apparent modulus	M_v (max)
NGC 121	V1	140	1.9	1.2–2.4	Bluer at maximum than at minimum	19.4	−4.0
ω Cen	V42	149	> 3.3		Redder at maximum than at minimum	14.0	−2.9
	SX Her	103	1.0	1.4–1.74	Bluer at maximum than at minimum		

Cen and SX Her. V1 NGC 121 lies between these two stars in period and amplitude. An important criterion for these stars is the phase relation of the $(B-V)$ variations. The TiO variables in ω Cen, including V42 (note, however, the uncertainty introduced by the close companion), are redder at maximum than at minimum. This is almost certainly due to the increasing importance of TiO blanketing towards minimum. In contrast, SX Her is bluer at maximum than at minimum (Preston *et al.*, 1963) (the star does however show TiO towards minimum). V1 NGC 121 is also bluer at maximum than at minimum. This, together with the very red colour at minimum $(B-V=2.4)$, presumably indicates that the star becomes very cool without TiO becoming strong. Unfortunately very little photometry is available for SRd variables in the Galaxy. Thus we cannot be sure whether there are galactic variables similar to V1 NGC 121 or whether the very red colour at minimum is a manifestation of a fundamental difference between variables of this general type in the Galaxy and in the SMC. However it seems that the variable may well be fitted into a general sequence of SRd variables. Preston and Wallerstein (1963) deduced a metal abundance of 1/50 solar for SX Her, and if the period is really an indicator of metal abundance one would expect V1 NGC 121 to be more metal rich than this. Tifft's (1963) colour-magnitude diagram for NGC 121 as well as the integrated spectral type (Andrews and Lloyd Evans, 1971) suggest that the cluster is of intermediate metal abundance, neither extreme halo nor extreme metal-rich (47 Tuc) type. The inferences about V1 are at least not inconsistent with this. Thus although I cannot at the moment point to a star in the Galaxy with exactly the same photometric properties as V1 NGC 121, I believe it would be premature to conclude that this type of object is unique to the SMC.

As shown in Table VIII, V1 NGC 121 is brighter at maximum than V42 ω Cen, and in the $V,(B-V)$ diagrams of these clusters V1 lies on a continuation of the giant branch at mean light whereas V42 ω Cen is well below the giant branch. These results may be connected with the effects of TiO blanketing in V42 ω Cen. In any case one should probably be prepared to accept a rather wide range of absolute magnitudes for SRd variables.

The present position regarding metal-rich clusters was summarized in an earlier section. For metal-poor clusters, the following seem to be outstanding points.

(1) There are semiregular variables near the giant tips in ω Cen and other metal-poor clusters. It is desirable to know much more about the periods and the precise

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positions of these stars in the HR diagram. For instance, one of the ω Cen stars lies below the giant branch for some unexplained reason.

(2) Very cool variables showing TiO occur in ω Cen. It would be important to find similar stars in other metal-poor clusters. It is not yet completely certain whether or not these stars have the same abundances as non-variable giants in ω Cen.

(3) The ω Cen work shows that even for metal-poor clusters effects on the photometry of the variables due to TiO blanketing may be present.

(4) The HR diagrams of ω Cen and 47 Tuc have different shapes in the red variable region.

(5) V1 NGC 121 in the SMC is an SRd variable which becomes very red at minimum. Further work on galactic SRd's is necessary before one can decide whether this is a peculiar property of the SMC or not.

Finally, I hope I have been able to show that one can make some rudimentary sense of the observations of slow variables in globular clusters. A number of correlations exist between the properties of the variables and the properties of their parent clusters. These correlations are still very tentative and much more detailed work is required to improve them. It is to be hoped that the next few years will see a considerable improvement in both the observational and theoretical position.

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DISCUSSION

Buscombe: (1) Is it not important to have quantitative measurements of equivalent width for (e.g.) TiO bands, from which abundance and temperature effects can be disentangled from broad-band photoelectric colour indices?

(2) Observers should always quote the date of colour measures for any type of variable star.

Schwarzschild: Dr Feast has I believe given us a remarkably systematic review of the variables at the top of the red giant branch in globular clusters. The data he gave seem to me most encouraging for the view that a star climbing up the red giant branch for the second time first becomes pulsationally weakly unstable, then as it rises, more and more unstable (longer periods, larger amplitudes), until during a pulsation the radius becomes dangerously large (very red minima), which finally should lead to the ejection of a planetary nebula.

Dickens: In connection with Prof. Swarzschild's remarks concerning the possibility of mass loss occurring in these very cool variables, the absorption lines in the spectra of some of the red variables in ω Cen, in particular V42, show a 'washed out' appearance, presumably similar to what has been observed in some field red variables. One possible explanation for this effect would be some absorption from particles high in the atmosphere or perhaps in a shell which has been ejected from the star.

Jones: Could you comment on the fact that Kinman did not record TiO in his spectra of giants in ω Cen?

Feast: Kinman had, I think, only one spectrum of a TiO variable (V42) near maximum. TiO is not strong on the plate, but if I remember correctly, it is rather over-exposed in the relevant spectral region. Generally I think Kinman kept away from the extreme giant tip in his work.

Jones: My radial velocities of M stars in the SMC reveal only one candidate for an analog to the ω Cen M stars, which is geographically in the halo. L^2 Pup is a much more obvious analog.

Wing: The absolute magnitudes of the Mira variables in 47 Tuc can hardly be fainter than $M_{bol} = -5.0$, to judge from the M_V's and spectral types you tabulated. With regard to their apparent V magnitudes, they may be brighter than giant-branch stars of the same $B-V$ color some of the time, as you commented, but most of the time they are below the giant branch. At minimum they reach $V = 15$ or 16 without much change in $B-V$.

Feast: The V magnitudes plotted in the diagram were time-averaged intensity values.

van den Bergh: You suggest that we might find a galactic counterpart to V1 in the SMC cluster NGC 121 *if* we look hard enough. But is it not true that such very red objects would have been found if they had been located in galactic globular clusters?

Feast: It does seem unlikely that there are any equivalent stars in galactic globular clusters, though only a few red giant variables in galactic globular clusters have $(B-V)$ colour curves.