UBV MAGNITUDES AND COLOURS OF 62 RR LYRAE STARS IN ω CENTAURI (NGC 5139)

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1. Introduction

It has been shown by the author (Geyer, 1967), and independently by Dickens and Woolley (1967), that there occur horizontal branch stars well within the RR Lyrae variable gap of the $c-m$-diagram of ω Centauri. Variability of these objects is not known, and presumably is unlikely, because the cluster is so well studied for variable stars. For the observationally best studied globular clusters M3, M13, M15 and M92 (Sandage, 1969), this phenomenon is *not* found. The author's original published $c-m$-diagram of NGC 5139 showed about 10 stars with $(B-V)\geqslant 0.2$ and V-magnitudes comparable with those of RR Lyrae stars of the cluster. Unpublished photoelectric measurements of some of these stars, carried out in 1968 with the 40-in photometric reflector of ESO by the author, support this finding. Also the study of blue horizontal branch stars by Newell, Rodgers and Searle (1969) of the Herstmonceux catalog of ω Centauri (Woolley *et al.*, 1966) confirms these results, the importance of which for the understanding of the horizontal branch stars and RR Lyrae variables is obvious.

2. Observations

UBV observations of larger samples of RR Lyrae stars in globular clusters have been published by Sandage (1959) for M3 and by Dickens (1970) for NGC 6171. Both clusters belong to Oosterhoff's 'short period group', whereas ω Cen is typical of the 'long period group'. As far as the morphology of the $c-m$-diagrams of globular clusters is concerned, ω Cen is between the M15/M92- and M10/M13-groups. For NGC 5139 intensity mean B, V values and colours based on photographic photometry for a larger number of RR Lyrae variables have been given independently by Dickens and Saunders (1965), and Geyer and Szeidl (1965, 1970). The latter observations are based on 38 plates in each colour obtained with the ADH-Baker-Schmidt camera of the Boyden Observatory, and on photoelectric standard stars which were also used for the *UBV*-photometry of the cluster (Geyer, 1967). These standards were also rechecked in 1968 at the European Southern Observatory. Several observers (see Newell *et al.*, 1969) have indicated that there exist systematic errors in the Herstmonceux photometry of NGC 5139, and these may also be responsible for the differences between our variable star photometry and that of Dickens and Saunders. On these plates 18 additional previously neglected RR Lyrae stars have been measured, especially V 68 which is an RR_c star with the extremely long period of $0^d.534$. These 62 RR Lyrae variables have now also been observed

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on 27 U-plates obtained with the ADH-camera in 1962–63 and 1968. The estimated internal errors of the intensity mean magnitudes V_d* are $\pm 0\overset{m}{.}02$; for $(B-V)_d$* $\pm 0\overset{m}{.}03$; and $\pm 0\overset{m}{.}04$ for $(U-B)_d$*.

3. Discussion

We now discuss the observations of the ω Cen variables in comparison with those of M3, and concentrate mainly on the $(U-B)_d$ colours. The $(B-V)_d$ colours have been discussed by Geyer and Szeidl (1965, 1970).

From the available data we derive for the ω Cen RR Lyrae variables the following mean values:

RR_{ab}-stars $(N=31)$:

$$\bar{P}_{ab} = 0\overset{d}{.}684;\quad \bar{V}_d = 14\overset{m}{.}45,\ \overline{(B-V)}_d = 0\overset{m}{.}336,\ \overline{(U-B)}_d = 0\overset{m}{.}292.$$
$$\sigma = \pm 0\overset{d}{.}104;\ \sigma = \pm 0\overset{m}{.}15,\quad \sigma = \pm 0\overset{m}{.}053,\quad \sigma = \pm 0\overset{m}{.}081.$$

RR_c-stars $(N=29)$:

$$\bar{P}_c = 0\overset{d}{.}379;\quad \bar{V}_d = 14\overset{m}{.}42,\ \overline{(B-V)}_d = 0\overset{m}{.}243,\ \overline{(U-B)}_d = 0\overset{m}{.}334.$$
$$\sigma = \pm 0\overset{d}{.}060;\ \sigma = \pm 0\overset{m}{.}13,\quad \sigma = \pm 0\overset{m}{.}052,\quad \sigma = \pm 0\overset{m}{.}068.$$

Two stars have been omitted because of uncertain photometry of the one (V 15) and the ultrashort period of the second (V 65), which is generally considered to be a foreground dwarf cepheid. These values are in good agreement with the photoelectric photometry of 10 RR Lyrae stars in ω Cen by Oosterhoff and Walraven (1966). The dispersions in magnitude and colour are due to photometric errors *and* intrinsic scatter.

A. THE $c-m$-DIAGRAMS

In the V_d, $(B-V)_d$ diagram the borders of the variable gap are practically identical on the red side for M3 and ω Cen, and only slightly shifted on the blue side for the ω Cen variables. Also both clusters have in common that the $(B-V)_d$ for RR_c stars is smaller than for the RR_{ab} variables, but only in ω Cen do both star types overlap in colour. Yet in the V_d, $(U-B)_d$ diagram the colour index is smaller for the RR_{ab} than for the RR_c stars. On the other hand the $(U-B)_d$ width of the variable gap is wider for NGC 5139 than for M3, and in addition its colour borders are shifted by up to $0\overset{m}{.}35$ to the red, as can be seen from Figure 1. The eclipsing variable V 78 (Geyer, 1971) is well situated within the RR Lyrae domain. Together with its photoelectrically derived colours this is an additional argument for its cluster-membership. V 92 is a $1\overset{d}{.}345$ Cepheid.

B. THE PERIOD-COLOUR RELATIONS

In the period- $(B-V)_d$ diagram of ω Cen the slope for the RR_{ab} stars is less steep than for the same variables in M3, whereas the slope for the RR_c stars is nearly

* V_d, $(B-V)_d$, $(U-B)_d$ are identical with $\langle V\rangle$, $\langle B\rangle - \langle V\rangle$, and $\langle U\rangle - \langle B\rangle$ respectively.

identical with that of M3. The previously suspected second RR_c branch parallel to the first one, but shifted to longer periods, has been confirmed by 7 additional RR_c stars, especially by V 68, which defines the upper end of this branch. This is of importance since it indicates that there is a mass range of the RR_c stars in ω Cen.

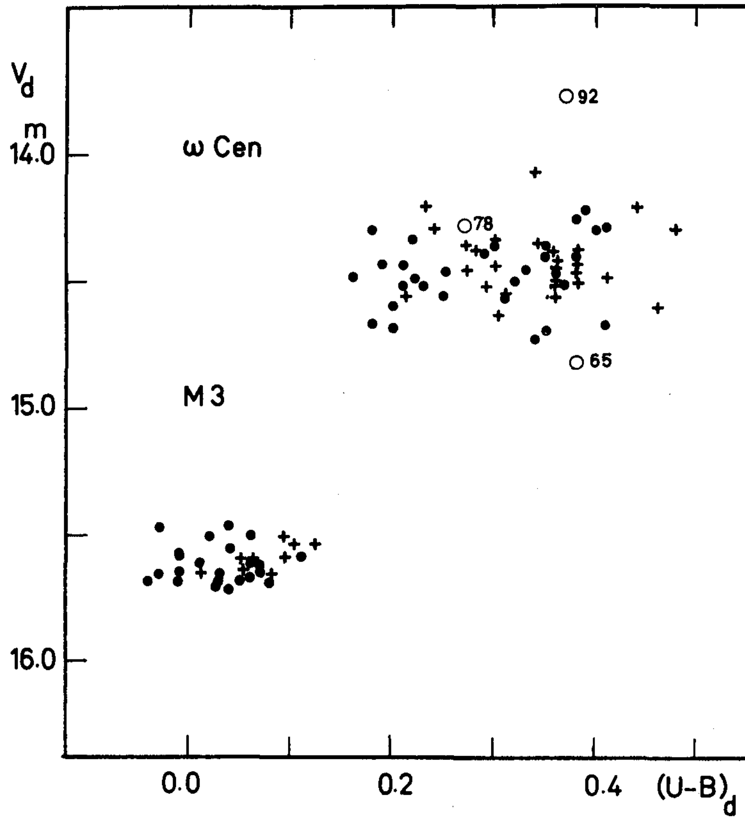

Fig. 1. The $(U-B)_d$-magnitude diagram for RR Lyrae variables of the globular clusters ω Cen and M3. Filled circles are RR_{ab} stars, crosses are RR_c stars. Star 65 is a 0ᵈ035 dwarf cepheid; star 78 is an EA binary and star 92 a 1ᵈ34 Population II-Cepheid.

As can be seen from the period- $(\overline{U-B})_d$ plot (Figure 2) no obvious period-colour correlation exists.

C. THE PERIOD-LUMINOSITY RELATION

It has been shown previously by Dickens and Saunders (1965), and Geyer and Szeidl (1965, 1970) that there exist period-magnitude relations for the ω Cen RR Lyrae variables. The additional observed variables strengthen this result as can be seen

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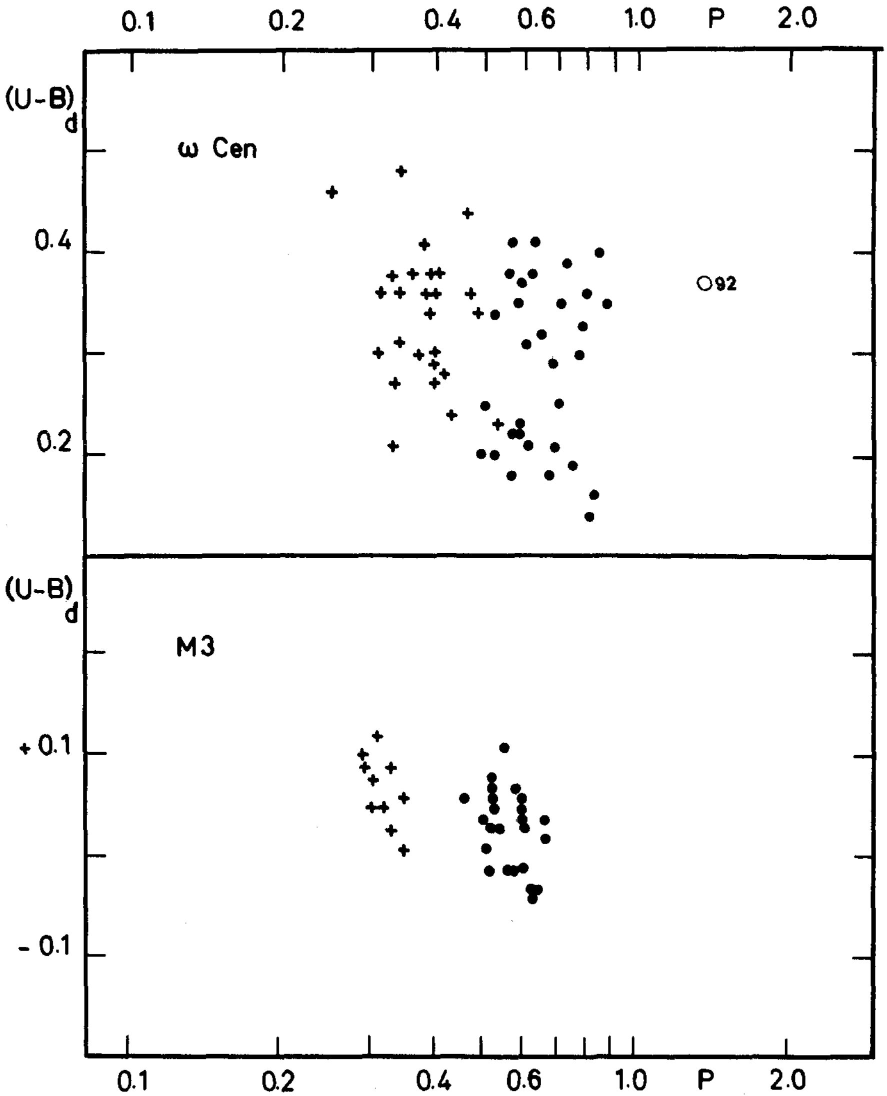

Fig. 2. The period-$(U-B)_d$ relations. Symbols as in Figure 1.

from the period-magnitude plot (Figure 3). The empirically derived relations are as follows:

ω Cen: RR_{ab} stars:

$$V_d = -1.99 \cdot \log P_{ab} + 1.83 \cdot (B-V)_d + 13.45.$$

RR_c stars:

$$V_d = -1.39 \cdot \log P_c - 0.13 \cdot (B-V)_d + 13.85.$$

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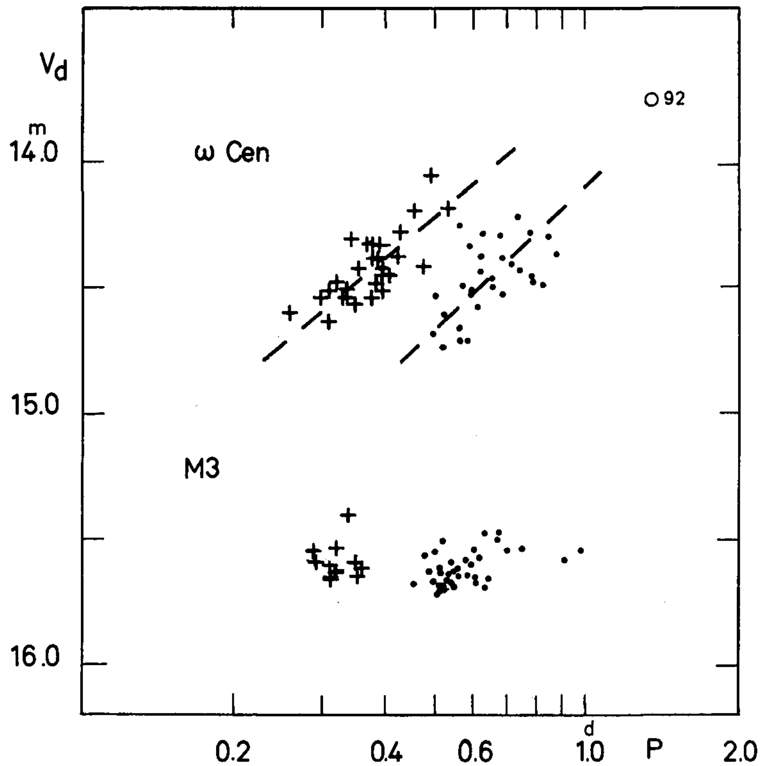

Fig. 3. The period-magnitude diagram for ω Cen and M3. Symbols as in Figure 1.

D. THE TWO-COLOUR DIAGRAM

In the two-colour plot (Figure 4) the M3-variables and horizontal branch stars show only a slight ultra-violet deficiency in comparison with the population main-sequence relation, and there is a quite smooth transition from non-variable to variable stars. This is also observed for the NGC 6171 stars (Dickens, 1970). The RR Lyrae variables of ω Cen behave quite differently, showing a *uv* deficiency amounting to $0\overset{m}{.}4$. Yet the majority of the blue horizontal branch stars which also overlap the variable gap in the $c-m$-diagram do *not* show such a large *uv*-excess. Only some of them coincide with the position of the RR Lyrae stars. They may therefore be candidates for variability. Actually one of them is the EA binary V 78, for which the author showed that the hotter, smaller and more luminous component of the system is intrinsically variable. It should be mentioned that a large *uv*-excess in some RR Lyrae field stars is reported by Sturch (1966) and recently by Stepień (1972).

We therefore come to the conclusion that the ω Cen RR Lyrae variables are in a quite different evolutionary stage, and show differences in their atmospheres compared to the adjacent horizontal branch stars.

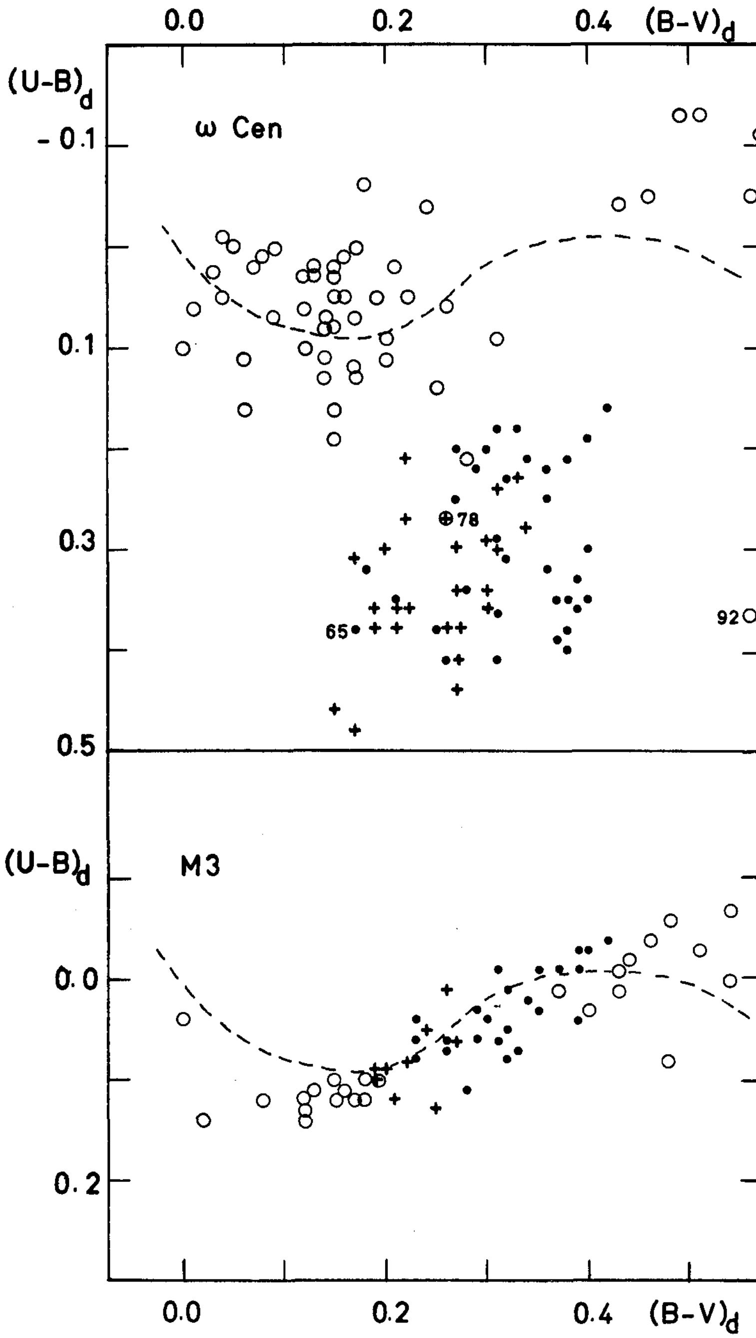

Fig. 4. The two-colour diagram for horizontal branch and RR Lyrae stars. Open circles are horizontal branch stars; other symbols are as in Figure 1.

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DISCUSSION

Jones: Christy predicts a complete absence of variables between 3/4 P_{tr} and P_{tr} ($P_{tr} = 0\overset{d}{.}565$ for ω Cen) but Dr Geyer's observations show a few variables in this range. Christy suggested that such stars might correspond to those of his models where both fundamental and first harmonic could be excited. Martin, in his Table II, lists 16 stars with irregular light curves in ω Cen, and 44 percent of them lie in Christy's gap. Of the remaining 109 RR Lyraes only 6 percent lie in the gap. While this is strong evidence of the simultaneous excitation of two modes, the boundary in period between types *a* and *c* is remarkably clear-cut. Of the *a* type, the shortest period with a regular light curve is No. 74 ($P = 0\overset{d}{.}503$) or with an irregular curve No. 112 ($P = 0\overset{d}{.}474$). The two longest period *c* type variables are No. 68 ($P = 0\overset{d}{.}534$) and No. 47 ($P = 0\overset{d}{.}485$). No. 68, of which special mention was made by Dr Geyer, has a proper motion indistinguishable from the other variables in the cluster. However it is 0.26 mag. brighter (m_{pg}) and may therefore not be a member.

Dickens: Mention was made in the paper of systematic error in the Herstmonceaux photometry of horizontal branch stars which was previously pointed out by the Stromlo workers. It should be noted that a comparison of the mean colours of variables in common between the work of Geyer and Szeidl and ours show a systematic difference in the run that Geyer and Szeidl's colours are in the mean 0.07 magn. *bluer* than ours, whereas those obtained at Stromlo for non-variables of a similar colour are somewhat *redder*. This remark is intended to illustrate and to emphasize the need for further work to decide whose colours (if any) are correct.