1974ApJ...192L.161H

THE ASTROPHYSICAL JOURNAL, 192:L161–L163, 1974 September 15
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THE UNUSUAL HORIZONTAL BRANCH OF NGC 2808

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Received 1974 May 28; revised 1974 July 1

ABSTRACT

A new color-magnitude diagram for the southern globular cluster NGC 2808 shows a peculiar "split" horizontal branch: both red and extremely blue HB stars are present, but a large unpopulated gap exists between them in the color range $-0.1 < (B - V)_0 < 0.4$. The cluster's giant-branch morphology and red HB are normal for a moderately high-metallicity object, but the presence of the extremely blue $[(B - V)_0 < -0.1]$ HB stars is anomalous. This feature is interpreted as due to a possible discontinuous mass distribution along the horizontal branch.

Subject headings: globular clusters — horizontal-branch stars

I. INTRODUCTION

The southern globular cluster NGC 2808 (α: 9^h10^m9; δ: $-64°39'$; 1950) is a spectacular object surpassed visually by only a few other clusters, such as 47 Tucanae or ω Centauri. The author has recently obtained a new color-magnitude (C-M) diagram for this object as part of a larger program on photometry of southern globular clusters. Although the complete details of the photometry will be published later for all the program clusters, the C-M diagram of NGC 2808 is of unusual interest, and some of the results are therefore discussed briefly here.

The present observations were obtained during 1973 April and May. The C-M diagram was derived from a set of photoelectrically calibrated photographic plates taken with the University of Toronto 61-cm telescope at Las Campanas, Chile. Three plates in V (103aD + RG495) and five in B (103aO + GG385) were measured with a Cuffey-type iris photometer at the David Dunlap Observatory. The photoelectric BV sequence used for the calibration consisted of 17 stars down to $V = 16.9$ mag measured at Las Campanas and Cerro Tololo; a previously published sequence by White (1970) was also used to give further weight to the calibration. The calibration was extended to the plate limit ($V_{\rm lim} \simeq 18.0$) through use of the secondary-image technique described by Harris and Racine (1974).

An area extending from 3′.0 to 6′.0 SW of the cluster center was measured on the plates; within this region, *every* visible uncrowded star was measured down to the limiting magnitude. This ensured that a complete and homogeneous sample of stars would be used to form the CM diagram.

II. THE COLOR-MAGNITUDE DIAGRAM

The resulting C-M diagram for the 300 measured stars is displayed in figure 1. A previous C-M diagram for NGC 2808 has been published by Alcaino (1971); however, the present study reaches more than 2 mag fainter and clearly reveals the nature of the horizontal branch for the first time. At $V \simeq 16.2$ and $B - V \simeq 0.7$, a heavily populated red horizontal branch (RHB) is seen well separated from the giant branch; and at $B - V \lesssim 0.1$, a scattering of extreme blue-horizontal-branch (BHB) stars is visible extending down to the plate limit. The internal random errors in the photometry at $V = 17$ are $\sigma(V) = \pm 0.06$ mag and $\sigma(B - V) = \pm 0.07$ mag, and are sufficient to account for most of the scatter present in this blue group. A moderate amount of field contamination is seen overall in figure 1, particularly for $B - V \gtrsim 0.5$.

The foreground reddening of NGC 2808 must be known before any further discussion can be made; this can be estimated in several ways. The integrated color and spectral type of the cluster give $E_{B-V} = 0.23$ (Harris and van den Bergh 1974; Racine 1973). A second estimate can be made by assuming that the intrinsic color of the *red* edge of the RR Lyrae gap is $(B - V)_0 = 0.42 \pm 0.03$ (Sandage 1969); since the RHB stars in figure 1 stop at $B - V = 0.68 \pm 0.02$, this gives $E_{B-V} \simeq 0.26$. Finally, various cosecant laws (Sandage 1972, 1973; McClure and Crawford 1971) give color excesses from 0.14 to 0.28. A mean estimate of $E_{B-V} = 0.24 \pm 0.03$ will be adopted here.

The shape of the giant branch and the presence of the RHB are typical of clusters of intermediate or moderately high metallicity. This also fits well with the cluster's integrated spectral type of F8 (Kinman 1959) or G0 (Andrews and Evans 1973). The three well-known parameters describing the height and slope of the giant branch (ΔV, $(B - V)_{o,g}$, S) are listed in table 1 for NGC 2808 and for three other intermediate-type clusters for comparison.

III. THE HORIZONTAL-BRANCH MORPHOLOGY

Though the RHB is a normal feature in clusters like NGC 2808, the extreme BHB is not. *All* the BHB stars in figure 1 are bluer than $(B - V)_0 \simeq -0.1$, and they fall on the normal blue extension of the HB which would usually be seen only in more metal-poor clusters like M15 or M92 (Sandage 1969). Furthermore, no HB stars fall *between* the extreme BHB group and the RHB (except possibly for one star at $V = 16.0$, $B - V = 0.35$, if, of course, it is not a field interloper). As for the RR Lyrae gap itself, at most nine RR Lyrae–type

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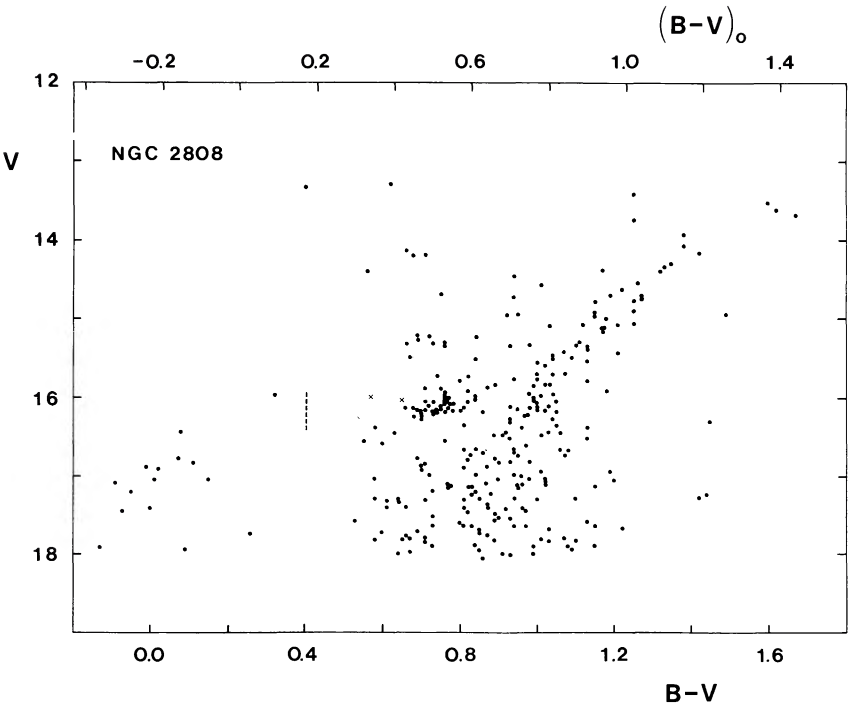

FIG. 1.—The C-M diagram for the photographically measured stars. The approximate mean positions of two measured RR Lyrae variables are shown by crosses, and the expected position of the blue edge of the RR Lyrae instability strip is indicated by a line at $(B - V)_0 = 0.17$.

TABLE 1

GIANT-BRANCH PARAMETERS FOR FOUR CLUSTERS*

Cluster	ΔV	$(B-V)_{0,g}$	S	Reference
M3............	2.73	0.81	5.0	Sandage 1970
NGC 2808......	2.53	0.76	4.1	This paper
NGC 6171......	2.40	0.90	4.5	Dickens and Rolland 1972
47 Tucanae.....	1.85	0.92	3.3	Menzies 1973

* Arranged approximately in order of increasing metallicity.

variables are known in the entire cluster (Sawyer Hogg 1973). One of these (V6) falls in the measured region, and another (V9) falls just outside. Their approximate mean positions are shown in figure 1, along with the expected position of the RR Lyrae strip's blue edge at $(B - V)_0 = 0.17$ (Sandage 1969). Both variables lie toward the red side of the gap, and appear to be just RHB stars which have evolved a short way into the instability strip.

Thus with the definite exception of a very few variables, there seem to be *no* cluster stars at all between $B - V = 0.10$ and $B - V = 0.65$. Even though the HB of NGC 2808 contains both red and extremely blue stars, the conclusion is clear that *the central part of the horizontal branch is completely missing.*

Recently, Newell (1973) has discussed the existence of two narrow "gaps" in the color distribution of field BHB stars. The first appears at $(B - V)_0 = -0.13$, $(U - B)_0 = -0.40$ ($\log T_e = 4.11$), and the second at $(B - V)_0 = -0.24$, $(U - B)_0 = -0.90$ ($\log T_e = 4.32$). These gaps break the HB stars into three natural groups which appear to differ in the type of evolutionary tracks they follow. Now remarkably, *the intrinsic color at which the extreme BHB stars in NGC 2808 first appear* (i.e., their "red edge") is $(B - V)_0 = (0.11 \pm 0.03) - E_{B-V} = -0.13 \pm 0.04$. Unfortunately only the photometry in two colors is presently available, but within the errors this corresponds perfectly to the location of Newell's "gap 1." It therefore seems natural to identify this extreme BHB group of stars with Newell's evolutionary group "BC." This will be discussed in the next section.

No other cluster is known to present such a striking example of a disconnected BHB. However, certain less obvious examples of this may exist in other roughly similar clusters. For instance, in the C-M diagram of 47 Tucanae (Menzies 1973) there is a single blue star which falls in the same region as the NGC 2808 BHB stars. NGC 362 (Menzies 1967) may also have a few such members. Clearly, more searches for this type of object would be valuable.

IV. DISCUSSION

Inspection of recent theoretical work on horizontal-branch models for globular clusters (Demarque and Mengel 1971, 1972; Rood 1973; Iben and Rood 1970) suggests several simple possibilities for explaining the "abnormal" presence of the extreme BHB stars in NGC 2808. These can be listed and commented on as follows.

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1. The extreme BHB stars might be RHB stars in a slightly later stage of evolution. This can be ruled out, since no single HB evolutionary track is remotely capable of covering such a wide gap (0.55 in $B - V$, or 0.35 in log T_e) *and* at the same time leaving the region between the two groups devoid of stars.

2. The BHB stars might have a radically different composition in the sense that either their heavy-element abundance Z is lower by a factor of ~ 10 compared with the RHB (assuming $Z \sim 10^{-3}$ normally for this type of cluster), or the helium abundance Y is far higher than any presently accepted value near the "normal" one of $Y \simeq 0.3$. This would require either local compositional variations within the cluster at its formation, or some peculiar interior mixing process. This hypothesis is extremely ad hoc, all the evolutionary models point against it, and it would not explain why such a *distinct* gap exists and why the extreme blue stars fall on the blue extension of the *normal* horizontal branch. Furthermore, if a large spread in Z were to exist within the cluster, the giant branch could not appear as narrow as it does (cf. Alcaino's C-M diagram).

3. The BHB stars might differ in *age* from the RHB group in the sense that they are significantly older and hence less massive. However, at $Z \simeq 10^{-3}$ this would require an age difference of more than $\sim 2 \times 10^9$ years (cf. Rood 1973), and would imply that two sharply distinct epochs of star formation took place within one cluster.

4. Finally, the BHB stars might be *less massive* than the RHB stars even though they are the same age. Partly by default, this seems to be the most plausible interpretation, but it fits in well with the current viewpoint of the HB as a mass sequence. Also, it meshes naturally with Newell's (1973) interpretation of HB morphology as mentioned earlier. Briefly, in this scheme all HB stars in a given cluster will have essentially the same helium-core mass M_c but differing envelope masses M_e. Where the stars sit on the HB is then determined by how much envelope mass they have lost in pre–HB evolutionary phases. All the stars on the low-temperature side of "gap 1" (i.e., redder than $(B - V)_0 = -0.13$) will evolve back toward the asymptotic giant branch, but the stars falling to the blue side of gap 1 cannot do this since M_e is too low. Instead, they will evolve upward and then to higher temperatures before becoming white dwarfs.

If this last interpretation is valid, one further inference may be drawn. Inspection of the theoretical models cited indicates that the RHB stars in NGC 2808 should have masses near 0.60 $M_\odot$, whereas the extreme BHB stars should then have masses ~ 0.10 $M_\odot$ less in order that all of them will fall to the blue side of the critical "gap 1" point. The huge unpopulated zone between the RHB and BHB groups would then demand that a curious process of differential mass loss is taking place among the cluster stars. Somehow a small fraction ($\sim \frac{1}{4}$) of the HB stars find a way to lose $\gtrsim$ 0.10 $M_\odot$ more from their envelopes than do the "normal" RHB stars, in such a way as to create a *discontinuous* mass distribution along the HB. This would be unlike any other observed cluster; and if true, the implications about mass loss on the giant-branch and horizontal-branch phases are clearly important.

One additional feature in the C-M diagram of figure 1 which may be of significance is the small "clump" of eight stars directly above the RHB, at $V = 15.5$ and $B - V = 0.65$. Some of these may, of course, be field stars, but those that are cluster members might be in an evolutionary stage *between* the RHB and the asymptotic branch proper. The evolutionary tracks for RHB stars of $\simeq 0.60$ $M_\odot$ (Demarque and Mengel 1972; Iben and Rood 1970) indicate that a post–RHB star may spend up to about a quarter of its RHB lifetime at a position 1 mag directly above the RHB before moving on to the asymptotic branch (depending on the physics of the models); so it seems likely that at least a few cluster members might be seen in this part of the diagram.

The C-M diagram of NGC 2808 is unique among globular clusters yet studied. Clearly this interesting object warrants further research from many approaches, to cast light on the speculations made here. The complete data for the C-M diagram presented here, including the finder charts and tables of photometric data, will shortly be submitted for publication along with material for several other clusters. Meanwhile, the author will send this information on request to any interested readers.

I am indebted to Drs. René Racine and Sidney van den Bergh for helpful comments on the manuscript. Financial support through the National Research Council of Canada is also gratefully acknowledged.

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