THE EVOLUTION OF THE INTEGRATED COLORS OF GLOBULAR CLUSTERS AND ELLIPTICAL GALAXIES

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I. INTRODUCTION

The purpose of this paper is to show the first results of a program designed to construct population models of stellar systems on the basis of theoretical data of stellar evolution. Synthetic HR diagrams were obtained using the isochrones and luminosity functions of Ciardullo and Demarque (1977). This last work is based on the stellar models of the Yale - IBM research group (Mengel, Sweigart, Demarque and Gross 1978; Sweigart and Gross 1976; 1978). The conversion from the theoretical HR diagram to observable parameters is made with the help of theoretical model stellar atmospheres principally due to Kurucz (1976), Relyea (1976) and Bell and Gustafsson (1975). The program provides a synthetic C-M diagram and integrated properties for the system given the following parameters: the chemical composition in terms of the (Y,Z) pair, the age, the total number of stars, the initial mass function (IMF) and the law of mass loss from stars in the system. In this brief paper, we shall concentrate on the integrated properties of theoretical star clusters and then remark on some interesting consequences for the color evolution of elliptical galaxies.

II. MODELS OF GLOBULAR CLUSTERS

We have considered two extreme chemical compositions, one corresponding to a very metal-poor stellar population with $(Y,Z) = (0.20, 10^{-4})$, the other characteristic of the metal-rich component of the galactic halo with $(Y,Z) = (0.30, 10^{-2})$. This last metallicity could also be considered representative of many of the stars in the galactic disk, except for some possible differences in the value of Y (Demarque and McClure 1977a, b). The

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IMF was taken to be the Salpeter (1955) function in the case illustrated in the figures. A standard law of mass loss due to a stellar wind, which is most effective at the tip of the giant branch (Heasley and Mengel 1971; Fusi-Pecci and Renzini 1975) was adopted. In addition we assumed a Gaussian dispersion in mass loss in order to obtain a small mass spread on the horizontal branch. The total number of stars was varied from 10^5 to 10^6. Fig. 1 shows the evolution in the two-color diagram of a metal poor system of 10^6 stars. Fig. 2 illustrates the same result for the metal rich cluster.

The necessity for including mass loss in the models is demonstrated in Figs. 1 and 2. It is well known that without mass loss the extremely luminous asymptotic giant branch stars dominate the light and render the system too red. In the present work, mass loss also affects the color evolution in an important way through its effect on horizontal branch morphology.

Racine's (1973) calibration of the intrinsic colors of galactic globular clusters is drawn on Figs. 1 and 2. On this curve the clusters form a sequence with the most metal poor systems occupying the blue end, the most metal rich lying at the red end. This is verified in a general way by our models. However, age effects are also striking and may be the cause for the intrinsic scatter noted by Racine (1973) in the relation between $(B-V)_0$ and metallicity. The loop described as a function of age in the two-color plane is the result of the inclusion of horizontal-branch evolution.

The globular clusters in M31 have been found by van den Bergh (1969) to have a brighter M_V (by 0.5 mag.) and a redder $(B-V)_0$

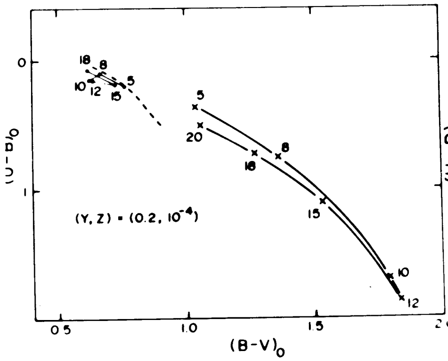

Fig. 1. Colors for metal-poor system as a function of age (in Gyrs) with mass loss (dots) and without mass loss (crosses). The dashed line is Racine's (1973) calibration.

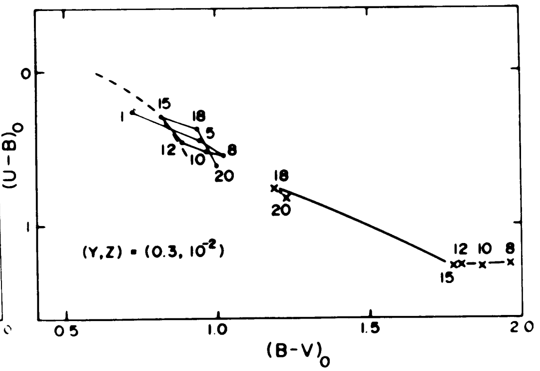

Fig. 2. Same as Fig. 1 for the metal-rich system.

(by 0.1 mag.) than their galactic counterparts. Van den Bergh (1969) then concluded that the M31 clusters are the more metal rich and the more massive. The same data also seem consistent with the alternative interpretation that the globular clusters in M31 are 3 Gyrs younger than those in our Galaxy.

Statistical fluctuations in the numbers of stars in rapid but luminous phases of evolution can be the source of larger uncertainties in color. Some of the model clusters for 10^5 stars confirm this. Fig. 3 shows an extreme example of this effect which confirms some earlier discussions by Racine (1975) of the clusters NGC 8749, NGC 7492 and Pal 13. It seems possible that the differences between the brightest red giants in the Fornax galaxy and its associated globular clusters (Hodge 1961) is due to a similar statistical effect.

III. COMMENT ON THE COLOR EVOLUTION OF ELLIPTICAL GALAXIES

The models for metal-rich systems presented here are also directly applicable to elliptical galaxies. Fig. 2 illustrates the interesting result that the integrated $(B-V)_o$ color does not necessarily increase monotonically toward the red as a function of time as found in current models of galaxies (Tinsley 1977; Tinsley and Gunn 1976; Prather 1976). In fact inclusion of the evolution of the horizontal-branch results in a loop in the two-color plane and in the possibility of blueward evolution with time. In fact in the age interval of 8 to 15 Gyrs, we find that:

$$\frac{\partial(B-V)}{\partial t} = - 0.03 \text{ Gyr}^{-1} \qquad (1)$$

Equation (1) is consistent with the observations of the color evolution of elliptical galaxies by Crane (1975), recently rediscussed by Oke and Wilkinson (1977). A more reliable estimate of equation (1) will require a better quantitative understanding of the role of mass loss in stellar evolution and of the theory of the horizontal branch. Financial support of this research by grant AST 72-04418 from the National Science Foundation is gratefully acknowledged.

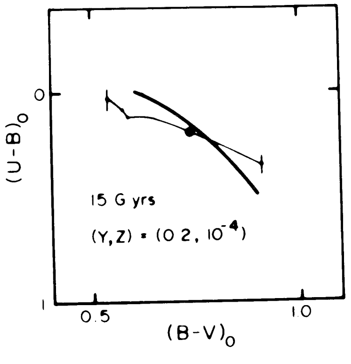

Fig. 3. Range of colors for a model system containing 10^5 stars.

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REFERENCES

Bell, R.A. and Gustafsson, B. (1975). In Multicolor Photometry and the Theoretical HR Diagram, A.G.D. Philip and D.S. Hayes, eds., Dudley Obs. Report No. 9, p. 319.
Ciardullo, R.B. and Demarque, P. (1977). Trans. Yale Univ. Obs. Vol. 33, 34, 35.
Crane, P. (1975). Astrophys. J. Letters 198, L9.
Demarque, P. and McClure, R.D. (1977a). Astrophys. J. 213, 716.
Demarque, P. and McClure, R.D. (1977b). Yale Conf. on The Evolution of Galaxies and Stellar Populations, B.M. Tinsley and R.B. Larson, eds., Yale Univ. Obs., New Haven, p. 199.
Fusi-Pecci, F. and Renzini, A. (1975). Astron. Astrophys. 39, 413.
Heasley, J.N. and Mengel, J.G. (1972). Observatory 92, 93.
Hodge, P.W. (1961). Astron. J. 66, 83.
Kurucz, R.L. (1976). unpublished.
Mengel, J.G., Sweigart, A.V., Demarque, P. and Gross, P.G. (1978). to be published.
Oke, J.B. and Wilkinson, A. (1977). to be published.
Prather, M.J. (1976). Ph.D. dissertation, Yale University.
Racine, R. (1973). Astron. J. 78, 180.
Racine, R. (1975). Astron. J. 80, 1031.
Relyea, L. (1976). Ph.D. dissertation, SUNY Albany.
Salpeter, E.E. (1955). Astrophys. J. 121, 161.
Sweigart, A.V. and Gross, P.G. (1976). Astrophys. J. Suppl. 32, 367.
Sweigart, A.V. and Gross, P.G. (1978). to be published.
Tinsley, B.M. (1977). to be published.
Tinsley, B.M. and Gunn, J.E. (1976). Astrophys. J. 203, 53.
van den Bergh, S. (1969). Astrophys. J. Suppl. 19, 145.

DISCUSSION

WEIDEMANN: Did you include differential mass loss besides the Fusi-Pecci/Renzini-type mass loss on the first giant branch in order to produce the horizontal branch?

DEMARQUE: A Gaussian distribution in the mass loss from individual stars was also included to obtain the derived spread in mass on the horizontal branch.

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