CURRENT PROBLEMS IN HORIZONTAL-BRANCH THEORY: SOME IMPLICATIONS FOR RR LYRAE VARIABLES.

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I. INTRODUCTION

There are a number of good reasons for wanting to improve our understanding of the structure and evolutionary status of horizontal-branch (HB) stars. To mention a few:

1) The HB morphology of globular clusters can be used as a tool for studying the evolution of the galactic halo (Searle and Zinn 1978) and the time scale for halo collapse (Demarque 1980; Zinn 1980).

2) HB stars offer an opportunity to evaluate the helium abundance of globular clusters. This can be done either by using the R-method (Cole et al. 1983) or the width of the RR Lyrae instability strip [Deupree 1977; but see also the paper by Stellingwerf (1984) in these preceedings which casts doubt on the validity of previous calculations of the dependence of the blue edge on helium content].

3) HB stars may play an important role in understanding the integrated light of old stellar systems. In particular, blue HB stars seem to make a significant contribution to the ultraviolet light of elliptical galaxies. (Ciardullo and Demarque 1978; Gunn, Tinsley and Stryker 1981). At the same time, HB stars are believed to be the direct progenitors of asymptotic giant branch stars which have proved to be powerful tracers of stellar populations in nearby external systems (Blanco et al. 1980)

4) The RR Lyrae variables are part of the HB population. One would wish to relate the observable properties of RR Lyrae variables to their chemical compositions and ages so as to use them: a) as distance indicators for galactic globular clusters (Sandage 1982a,b) and in the Magellanic Clouds; b) as tracers of stellar populations. This has been attempted for the galactic halo and disk by Sandage (1982a,b) and for the Magellanic Clouds by Butler et al. (1982).

The current theory of the HB [see e.g. the grid of HB evolutionary tracks by Sweigart and Gross 1976 (SG)], explains many features of HB morphology. It can, for example, be used to model the stellar distribution of the HB of most observed globular clusters and to describe the effects of age and chemical composition on HB morphology (Demarque 1980).

However, in the light of the new observational and theoretical information of the last few years a reevaluation of some aspects of the standard picture of stellar evolution in globular clusters is

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needed. The aim of this paper is:
1) to draw attention those features of HB theory which will require revision. Some of these changes are suggested by more refined observations; others by advances in stellar structure theory (Section II);
2) to discuss briefly the implications of recent observations of clusters main sequences in the Magellanic Clouds which have a direct bearing on the problem of the cosmological distance scale and should serve as a check of RR Lyrae absolute magnitudes and the zero-point of the Cepheid period-luminosity relation (Fernie and McGonegal 1983) (Section III).

II. DEFICIENCIES IN THE STANDARD THEORY

A growing number of questions are being asked about the HB which cannot be answered by the standard theory. In some cases, there are apparent inconsistencies; in other cases, the theory is incomplete. The list of these problems includes:
1) the anticorrelation of Y and Z among globular cluster variables of different chemical compositions discussed by Sandage (1982a,b), which is nearly certainly spurious.
2) our inability to understand the evolutionary status of the bluest HB stars, which are not found in the most metal-poor globular clusters, but rather in systems of intermediate metallicity (Sweigart et al. 1974; Caloi et al. 1984).
3) the problem of the evolutionary status of metal-rich RR Lyrae variables (Taam et al. 1976) which is still very uncertain, and the related more general question of the expected range in ages of RR Lyrae stars in different metallicities.
4) the origin of bimodal stellar distributions on the HB's of some globular clusters and the relation that these bimodal distributions have to similar bimodal distributions in the chemical composition observed on the giant branch of these clusters (Harris 1974; Freeman and Norris 1981). It has been suggested that internal stellar rotation plays an important role in this problem. This suggestion gains additional support from recent observations of surface rotation among blue HB stars (Peterson 1983).

The solution to problem 1) may be found in improved interior opacities (Renzini 1983). Another possibility is mixing of heavy elements produced at a particularly violent core helium flash (Deupree and Cole 1983). Still another is the possibility of a range in core masses (possibly due to internal rotation) among HB stars of the same composition.

Problems 2) and 3) seem primarily due to our inability to predict mass loss rates and their dependence, if any, on metallicity for late-type stars. Recent work by Dupree et al. (1984) suggests that previously derived mass loss rates for metal-poor giants were overestimates. This is one of several hints that one may have to have recourse to a mass ejection mechanism effective in the subgiant region to explain the low masses of HB stars compared to their main sequence progenitors

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(Dearborn et al. 1976; Corbally 1983; King et al. 1984).

On the theoretical side, arguments have been presented which cast doubt on the treatment of semi-convection first introduced by Robertson and Faulkner (1972) and used in the SG models (Arimoto 1980). At the same time, the rapid advances in numerical fluid dynamics have made it possible to reconsider the development of the helium core flash using a 2D and 3D description of convection (Deupree and Cole 1983; Deupree 1984). Although still subject to considerable uncertainties in their detailed predictions, the hydrodynamic core flash calculations demonstrate the need for a revision of the structure of ZAHB models. Some of their implications on HB Lifetimes and trach morphology have been discussed by Demarque (1981) and Cole and Demarque (1984).

III. STELLAR EVOLUTION, H_o AND THE DISTANCE TO THE MAGELLANIC CLOUDS.

Finally, I wish to discuss briefly recent observations of star clusters in the Small and Large Magellanic Clouds which, when interpreted with theoretical isochrones, lead to an apparent inconsistency with similar results from our own Galaxy in estimating the cosmic distance scale and the corresponding value of H_o. The current controversy between proponents of the "short" and "long" distance scales of the Universe is well known (Hodge 1981). It is also well known that a fit of galactic globular cluster c-m diagrams to theoretical isochrones yield ages which agree with the "long" estimate of the distance scale and are inconsistent with the "short" distance scale (or $H_o \cong 100$ km/sec Mpc) (Janes and Demarque 1983; VandenBerg 1983).

On the other hand, the recent c-m diagrams of the intermediate age clusters Kron 3 (Rich et al. 1984) and Lindsay 113 (Mould et al. 1984), both in the SMC, which include a sufficient portion of the main-sequence to achieve a good fit to the Yale isochrones (Ciardullo and Demarque 1979), are compatible with a distance modulus of 18.8 (i.e. the "short" distance scale). Similar work on two LMC clusters (NGC2162 and NGC2190) by Schommer et al. (1984), yields $(m-M_o)=18.2 \pm 0.2$ for the LMC distance modulus, also in agreement with the "short" distance scale using both the Yale isochrones and the work of VandenBerg and Bridges (1984).

We are thus left with the paradoxical situation that stellar models, based on the same theoretical assumptions, when applied to globular star clusters in the galactic halo on the one hand, and to old disk clusters in the Magellanic Clouds on the other hand, yield apparently inconsistent results for the age of the Universe, i.e. a high nuclear age, and a low expansion age.

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