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THE Hβ INDEX AND THE AGES OF OLD STELLAR SYSTEMS

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ABSTRACT

The Hβ and some metal line indices, such as Mg2, Fe52, Fe53 of single-age and single-metallicity populations are computed based on the method of evolutionary population synthesis, with careful consideration of the variation of the horizontal-branch morphology with metallicity and age. We find (a) that while metal lines are little affected, the Hβ index is severely enhanced (up to 30%) by the presence of the blue horizontal-branch stars, frustrating the current age-estimations from this index without careful consideration of these stars, and (b) that there is a systematic trend in the sense that the globular clusters in giant elliptical galaxies appear to be older than those in our Galaxy by several billion years. We also calculate these indices for the stellar populations with a metallicity spread, by adopting metallicity distribution functions predicted by chemical evolution models. The comparison of the models with the observed indices of the central regions of the early-type galaxies yields the results (a) that the ages of the giant elliptical galaxies would be older than the previous estimations by several billion years, and (b) that there is a considerable age spread among elliptical galaxies, in the sense that the giant elliptical galaxies are older than the small ones.

1. INTRODUCTION

The study of the integrated spectral line indices provides a powerful tool in investigating the evolution of stellar populations in remote systems, where the individual stars are below the detection limit of the present-day telescopes. Among various absorption features in optical range, the Balmer lines, in particular Hβ, are of strategic importance in the study of integrated spectra of stellar populations, because the Balmer lines are the most readily detectable age-sensitive features (Rabin 1982, Worthey 1994). A controversy has arisen over this index, however, regarding the possible contributions from other warm stars, such as blue horizontal-branch (BHB) stars (Burstein *et al.* 1984, Bressan *et al.* 1994, Vazdekis *et al.* 1996). In this respect, this study focuses on the behavior of the Hβ line strengths of globular clusters and elliptical galaxies with variation of the horizontal-branch

(HB) morphology, and on the question whether the Hβ index serves as an age indicator of the old stellar systems or not.

The following section describes the basic assumptions in our models. In sections 3 and 4, we show the variation of the Hβ index with metal lines, and compare our models with the observational data of globular clusters and elliptical galaxies, respectively.

2. POPULATION MODELS

The construction of models are divided into four parts: the H-R diagrams, a flux library, absorption line strengths, and a metallicity spread. For the evolutionary phase from the bottom of the main sequence to the tip of the red giant branch (RGB), the present models use the Yale Isochrones 1996 (Demarque *et al.* 1996), together with the low-mass main sequence tracks (Vanden Berg *et al.* 1983) to extend the isochrones down to $0.1M_{\odot}$. We adopt the standard Salpeter initial mass function (x = 1.35) over the whole mass range. For metal-rich ([Fe/H] $\geq$ -0.5) populations, we assume the galatic He enrichment parameter, $\Delta Y/\Delta Z$ = 2. For the evolutionary phase beyond the tip of the RGB, we use post-RGB tracks by Yi *et al.* (1997). In practice, we have used the techniques developed by Lee *et al.* (1994), but adopted the Reimers' (1975) empirical formula for the mass loss. The mass loss efficiency parameter has assumed to be $\eta = 0.5$ (see Yi *et al.* 1998).

To derive observational properties from the H-R diagrams, a flux library is needed that covers sufficient ranges of stellar luminosity, temperature, gravity, and composition. As no observational library of stellar spectra exists which covers the entire parameter space spanned by the distributions of the model stars, we have used the model atmospheres prepared by Lejeune *et al.* (1997) (see their Figure 1). We have used the recent empirical calibrations of absorption line strengths compiled by Worthey *et al.* (1994) to reduce the possible errors stemming from the use of purely theoretical fluxes. The calibrations are presented in forms of analytical fits that give the index strength as functions of stellar atmospheric parameters. Each star (from MS to post-RGB phase) yields a spectral energy distribution from the flux library, and the fitting functions give the strength of each absorption feature.

On the other hand, since real galaxies are believed to be represented by composite stellar populations with a metallicity spread (Rich 1988, Freedman 1989), we utilize metallicity distribution functions derived from the chemical evolution models of Arimoto & Yoshii (1987).

3. THE Hβ INDEX OF GLOBULAR CLUSTERS

Globular clusters are the cornerstones for our understanding of the integrated properties of the old stellar populations. We now compare the predictions of the simple stellar population models with the observations of the line strengths of globular clusters in several galaxies.

Due to its sensitivity to the temperature, the Hβ line is generally believed to be main-sequence turn-off temperature indicator (*e.g.* Worthey 1994). However, as claimed by several investigators (Bressan *et al.* 1994, Buzzoni *et al.* 1994, Vazdekis *et al.* 1996, Lee *et al.* 1996), the BHB stars may provide a substantial contribution to hydrogen absorption features. Thanks to the advent of large ground-based telescopes and to parallel progress in theoretical calculations of evolutionary tracks,

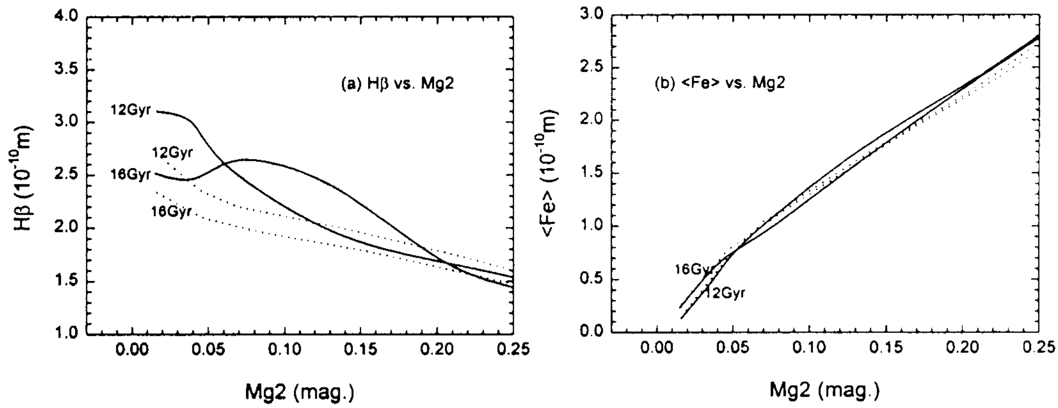

Figure 1. The Hβ index and the <Fe> index as a function of the Mg2 index at 12Gyr and 16Gyr. The solid lines and the dotted lines are the model predictions with and without inclusion of HB stars, respectively.

it is now possible to attempt to examine the globular cluster ages with the new population models that include the contribution from HB stars. In Figure 1, we show the Hβ index and the <Fe> index (=(Fe52+Fe53)/2) as a function of the Mg2 index at different ages. The solid lines and the dotted lines are the prediction by models with and without inclusion of HB stars, respectively. It is clear that while the <Fe> strength are little affected, the Hβ strength is significantly enhanced (up to 30%) by the presence of the BHB stars, so that the iso-age Hβ sequences do not monotonically decrease but they cross one another, making it difficult to extract an age of an individual cluster directly from the model grids. Figure 2 displays the distribution of globular clusters in the Milky Way (Cohen *et al.* 1998), M31 (Huchra *et al.* 1996), M87 (Cohen *et al.* 1998), and NGC1399 (Kissler-Patig *et al.* 1998) on the Hβ-Mg2 plane, compared with our models. In the light of the present models, the enhanced Hβ strengths of the metal-rich (Mg2$\geq$0.1) clusters in M87 and NGC1399 might be due to the presence of BHB stars, rather than due to their young ages. Furthermore, there is an important systematic trend in the distribution of Hβ indices of globular cluster systems of different parent galaxies, in the sense that the globular clusters in M87 and NGC1399 tend to populate along with old-age model sequences. This trend strongly suggests that the globulars in giant elliptical galaxies, such as M87 and NGC1399 are a couple of billion years older than those in our Galaxy.

4. THE Hβ INDEX OF ELLIPTICAL GALAXIES

Recently, several investigators, using simple stellar population models, reported that the Hβ index of elliptical galaxies may suggest that the early-type galaxies formed a significant fraction of their stars within the last 3$\sim$8Gyrs (Buzzoni *et al.* 1992, 1994, Worthey *et al.* 1992, González 1993, Faber *et al.* 1995). Others take into account the spread in metallicity expected in ellipticals, to produce similar results (*e.g.* Bressan *et al.* 1994). But, none of the previous composite population

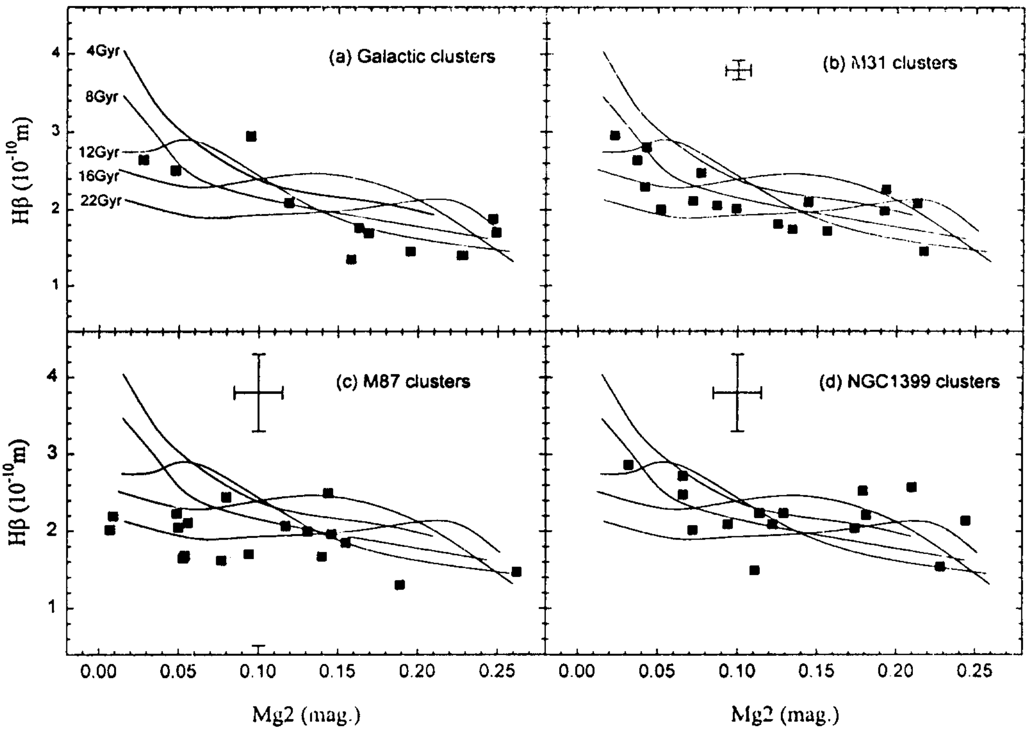

Figure 2. The Hβ indices of globular clusters in four different galaxies as a function of the Mg2 indices. The model predictions are presented by solid lines. The ages are indicated at the left end of each curves in panel (a).

synthesis models include a detailed treatment of the post-RGB stars, despite the fact that there exists strong evidence from UV radiation that hot HB stars should reside in ellipticals.

In Figure 3, we show the distribution of the line strength indices for the central regions of elliptical galaxies on the Hβ-<Fe> plane with our model grids. The Mg2 index of elliptical galaxies suffers from non-solar [Mg/Fe] ratio so here we adopt the <Fe> index. The observational data used in the plot are from González (1993), and among them, normal galaxies, that are not believed to experience recent star-burst, are selected according to Burstein *et al.* (1988). From Figure 3, it is clear that the luminosity-weighted mean ages of normal ellipticals are considerably (by 3Gyrs) older than previous estimates (*e.g.* Faber *et al.* 1995). Furthermore, there is a sizable age spread among normal galaxies, in the sense that the more massive galaxies are older than small galaxies.

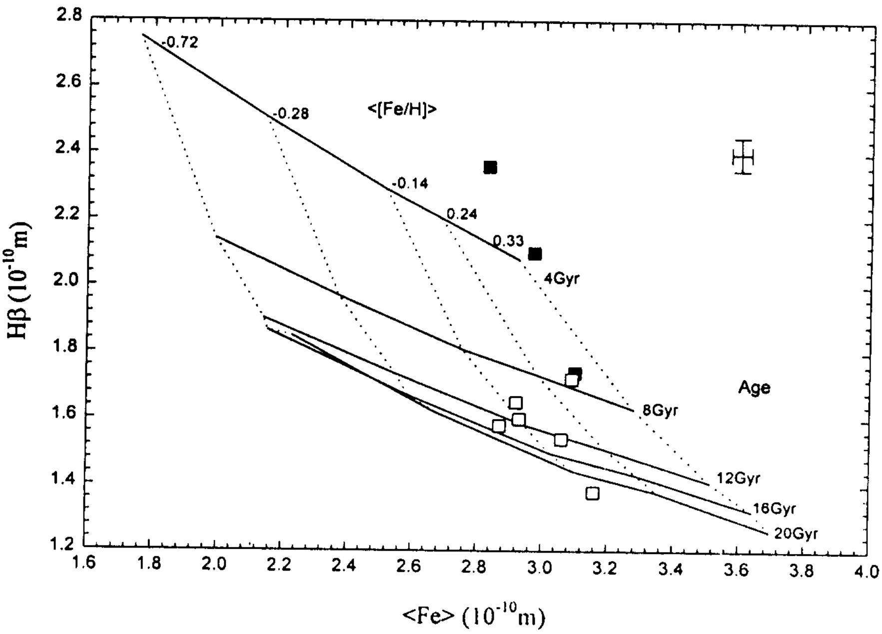

Figure 3. The Hβ vs. <Fe> correlation for the central regions of normal elliptical galaxies. The galaxies with $\sigma < 200kms^{-1}$ and $\sigma > 200kms^{-1}$ are presented by solid squares and open squares, respectively. A model grid from our composite stellar population models is overlaid. The solid lines are iso-age loci while the dotted lines are iso-metallicity loci. The values of <[Fe/H]> and age are indicated.

5. SUMMARY

The present models were constructed by using our evolutionary population synthesis code, including detailed horizontal-branch morphology variations with metallicity and age, and the effect of metallicity spread expected in galaxies. The results of our analysis based on this models are summarized as follows: By comparison SSP models with the globular cluster data, we have found (a) that besides the age, the presence of BHBs are also significantly responsible for the enhancement of the Hβ strength, and (b) that the globular clusters in giant elliptical galaxies are a couple of billion years older than those in the Galaxy. Comparison of CSP models with the normal elliptical galaxy data have revealed (a) that the the luminosity-weighted mean ages of normal ellipticals have been underestimated, due to the lack of consideration of HB stars, and (b) that there is a real age spread among normal galaxies, with more massive ellipticals being older than smaller ones.

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