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AGES OF ELLIPTICAL GALAXIES FROM POPULATION SYNTHESIS MODELS

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ABSTRACT

New population synthesis models, with the effects of metallicity spread and the horizontal-branch (HB) morphology, provide a way to break the well-known age-metallicity degeneracy in the analysis of the integrated light of elliptical galaxies. Our models suggest that the far-UV radiation of these systems is dominated by a minority population of metal-poor, hot HB stars and their post-HB progeny, while the optical radiation is dominated by a metal-rich population. The systematic variation of UV upturn depends on the contribution from metal-poor, hot HB stars and their post-HB progeny, which in turn depends on the ages of old stellar populations in galaxies. Our result implies a prolonged epoch of galaxy formation, in the sense that more massive galaxies (in denser environments) formed first. Our models also suggest that the strenghth of H_β index is strongly affected by HB stars, and hence previous age estimation without detailed modeling of the HB would underestimate the ages of ellipticals by ~7 Gyr.

Key Words : elliptical galaxies, horizontal-branch stars, ultraviolet: galaxies

I. INTRODUCTION

Ever since the discovery of two stellar populations by Baade (1944), both globular clusters and elliptical galaxies are considered as old Population II stellar systems. It is still not clear, however, whether there is any age difference, in the mean, between the Galactic globular clusters and elliptical galaxies; and it is also not clear whether there is any sizable age spread among elliptical galaxies. These topics on the ages of globular clusters and elliptical galaxies are of considerable importance, because they would have significant implications on the formation of galaxies and on the cosmological time scale test.

As is well known, globular clusters can be approximated as simple stellar populations having single age and metallicity, and hence their ages can be estimated from the luminosity of the main-sequence turn-offs by comparing the observations with the theoretical isochrones. In the case of elliptical galaxies, however, the situation is far more complicated, because (1) the ellipticals can not be considered as simple stellar populations but the internal metallicity spread must be taken into acconut, and (2) the ages of stellar populations in ellipticals must be derived from the analysis of integrated light. As demonstrated by many authors (e.g., Worthey 1994), the most serious problem in the interpretation of the observed spectral energy distribution (SED) is the age-metallicity degeneracy, i. e., age and metallicity have similar effects on optical broadband colors and absorption features. In the present paper, we show that more realistic models, with the effects of metallicity spread and horizontal-branch (HB) morphology, provide a way to break this degeneracy in the far-UV, and thereby throwing new light in exploring the ages of elliptical galaxies.

II. NEW POPULATION SYNTHESIS MODELS

In order to understand the stellar populations in elliptical galaxies from the observed SED, we have constructed new evolutionary population synthesis models. The reader is referred to Park & Lee (1997) for details of our model construction, and here we just describe the most important features of our models. Our models are based on the recent stellar evolutionary tracks from the main-sequence (MS) to the post asymptotic giant-branch (PAGB) stars (Green et al. 1987; Schonberner 1983), including the crucial HB and the post-HB phases (Lee & Demarque 1990; Dorman et al. 1993). The construction of SED is based on the Kurucz (1992) model atmospheres, which contain SEDs over a wide range of gravities, T_{eff}'s, and metallicities. As in the previous works by other model builders, we have adopted the Salpeter (1955) initial mass function with the standard Salpeter index (x=1.35). The internal metallicity distribution functions for elliptical galaxies are adopted from the chemical evolution models of Arimoto & Yoshii (1987). Consequently, our models supersede the previous ones by including (1) the detailed modeling for the HB and the post-HB phases, and (2) the effect of metallicity spread and corresponding variation in H-R diagram morphology. Most of the previous works have been done without careful considerations of these two crucial effects.

If, as we assumed, the star formation in normal elliptical galaxies can be approximated as initial burst, a model elliptical galaxy is nothing but a composite of models for simple stellar populations, weighted according to the given metallacity distribution function. Such composite models are presented in Figure 1, where we can see that the far-UV flux increases with increasing age, and that the age effect is more important than the metallicity effect in the far-UV spectra. Our models suggest that the far-UV radiation is dominated by a minority population of metal-poor, hot HB stars and their post-HB progeny, while the optical radiation is dominated by a metal-rich population. The systematic variation of UV upturn, therefore, depends on the contribution from metal-poor, hot HB stars and their post-HB progeny, which in turn depends on the ages of old stellar populations in galaxies. There is now a growing body of evidence from CCD photometry of globular clusters that, for a given metallicity, the HB morphology is most sensitive to age (see Lee et al. 1994 for a recent review). Superimposed on our models are IUE spectra of Burstein et al. (1988) for three elliptical galaxies that span maximum ranges in Mg_2 (mean metallicity) and central velocity dispersion (total mass). For each galaxy, the comparison is made with the model sequence that closely reproduce the observed metallicity (Mg_2 index) of a given galaxy. It is clear that our models reproduce (1) the general features of observed SEDs including the 2500Å dip, and (2) the systematic variation of UV upturn in terms of age variation among galaxies, in the sense that more massive galaxies are older.

III. DISCUSSION

From the comparison of our models with the far-UV observations, we estimate that the giant ellipticals are some 3 Gyr older than the spiral bulges of the Local Group (M31, Milky Way), while dwarf ellipticals, such as M32, are several billion years younger (see Park & Lee 1997). This would suggest that the giant ellipticals are as old as 19 Gyr. This is apparently in conflict with the recent result based on H_β line strength (Faber et al. 1995 and references therein), where they obtained fairly young ages for ellipticals (i.e., ~12 Gyr for giant ellipticals and considerably younger ages for dwarf ellipticals). Their analysis was based on the population models of Worthey (1994) compared to the observational data of Gonzalez (1993). As emphasized by Ferguson (1995), however, the effects of HB morphology and metallicity spread are not included in the population models of Worthey (1994); and it is interesting, therefore, to see how our models (with the effects of HB morphology and metallicity spread) predict the H_β and other optical features. Indeed, the preliminary models by Lee, Lee, & Park (1996, this volume), suggest that the strenghth of H_β index is strongly affected by HB stars, and hence the age estimation without careful consideration of these effects would underestimate the ages of ellipticals by up to ~7 Gyr. We believe, therefore, that the analysis based on the H_β index is not necessarily in conflict with our result from far-UV SED.

In addition to the systematic variation of far-UV radiation among galaxies, a similar systematic effect is observed within individual galaxies. According to the

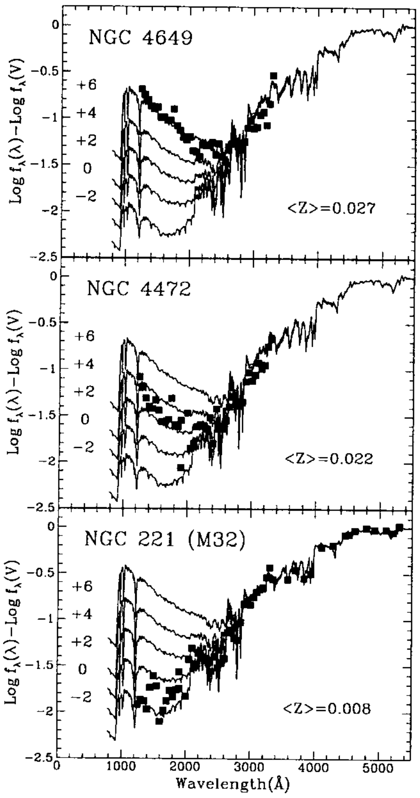

Fig. 1.— Composite SEDs of model elliptical galaxies for Δt = -2, 0, +2, +4, and +6 Gyr under different assumptions regarding the metallicity distribution function (and hence mean metallicity <Z>). Note that the strength of UV upturn increases with age. Far-UV SED's of three quiescent galaxies (IUE data from Fig. 4 of Burstein et al. 1988) that span maximum ranges in Mg_2 and central velocity dispersion are compared with our composite models (adopted from Park & Lee 1997).

Ultraviolet Imaging Telescope observations during the Astro-1 space shuttle mission (O'Connell et al. 1992), the far-UV colors become bluer with decreasing galactocentric distances for most galaxies (see Fig. 2). According to our models (see the solid & dashed lines in Fig. 2), the most natural interpretation of this trend is age gradient within the early-type systems, much like the inside-out picture for the bulge and halo formation of our Galaxy as suggested by Lee (1992) and Lee et al. (1994). The trend in the dwarf elliptical galaxy M32 is just opposite, which we think is evidence that the formation process for dwarf ellipticals was quite different from that for more massive galaxies. In fact, this could be understood if more massive galaxies (including our own) formed as clusters and mergers of many dwarf galaxy-size gas-rich subsystems, while in the outer halo,

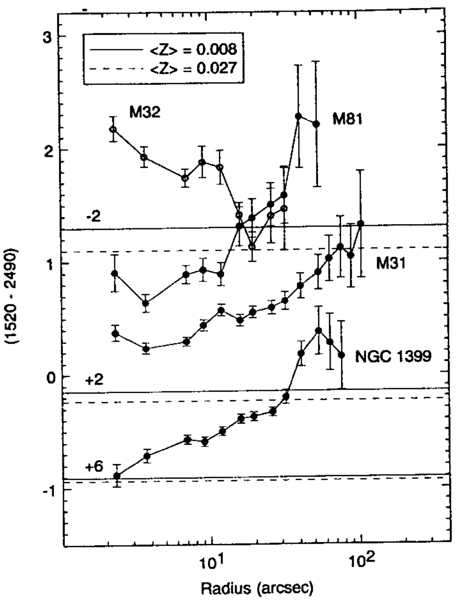

Fig. 2.— Far-UV color gradients within the early-type systems observed by the Ultraviolet Imaging Telescope (O'Connell et al. 1992). The solid & dashed lines are constant age lines based on our models in Fig. 1.

these subsystems evolved more or less independently and became dwarf elliptical or dwarf spheroidal galaxies that we observe today. It is encouraging to see that recent HST observations of high redshift sub-galactic clumps (Pascarelle et al. 1996) provide a direct evidence for this picture.

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