The Ages of Early-Type Galaxies: A Cautionary Tale

S. C. Trager

The Observatories of the Carnegie Institution of Washington, 813 Santa Barbara Street, Pasadena, CA 91101 USA

Abstract. Early-type galaxies are not the simple Population II systems they have long been assumed to be. While upwards of 80% of the stellar mass of early-type galaxies likely formed at high redshift, small frostings of intermediate-age stellar populations (a few to 20% percent by mass of 1–2 Gyr old stars) are present in nearly every field and group early-type galaxy and in at least some cluster early-types. These frostings of young stars have little effect on the determination of photometric redshifts, thanks to the age-metallicity degeneracy of broad-band colors, but even mild bursts of star formation at modest redshifts (a few tenths) may make identification of the progenitors of today’s early-type galaxies difficult at cosmological distances.

1. Introduction

A driving force behind the present explosion in the use of photometric redshifts is the need to “preselect” samples of interesting galaxies (often at specific redshifts) from photometric catalogs for further study. Early-type galaxies have a pronounced photometric signature—a strong Balmer break at 4000 Å and red colors longward of this—and thus are easily identified and their redshifts determined from imaging surveys. Studying the evolution of early-type galaxies from relatively high redshift ($z \sim 1$) to the present should thus be rather simple, once a reasonably large sample of galaxies at various redshifts are found.

This type of evolutionary study is predicated on a shaky assumption: early-type galaxies are passively evolving, old stellar systems, an assumption based on the suggestion by Baade (1963) that elliptical (and by extension S0) galaxies are Population II systems. Since the early 1970’s (e.g., Faber 1972, 1973; O’Connell 1980) it has been clear that most elliptical galaxies have too much blue light to be completely old populations. However, age and metallicity are nearly degenerate in the spectra of old ($> 2$ Gyr) populations, and sophisticated models and sensitive observations are required to break this degeneracy.

In this talk I present evidence that the excess blue light in early-type galaxies is due to small frostings of intermediate-age ($\sim 1$ Gyr old) stars. As these small frostings imply at least mild starburst events at moderate redshifts ($z \sim 0.1–0.3$), the assumption of passively evolving early-type galaxies—especially in the field and in groups—needs to be re-examined when interpreting the results of photometric (and spectroscopic) redshift surveys.
2. Breaking the Age-Metallicity Degeneracy

As demonstrated in Figure 1, most broad-band colors (particularly those longward of the 4000 Å break) and metal-line strengths are dominated by the light of the RGB of an old stellar population. Unfortunately, the RGB temperature (color) is degenerate to compensating ages in age and metallicity. This is the origin of the notorious age-metallicity degeneracy (Faber 1972, 1973; O’Connell 1980; Rose 1985; Renzini 1986). This degeneracy is actually quite helpful when determining photometric redshifts (Kodama, this volume), but not when attempting to determine the evolutionary histories of early-type galaxies.

However, Figure 1 also demonstrates a way to break this degeneracy: any color or absorption-line strength sensitive to the temperature of the main sequence turn-off (MSTO) will be much less sensitive to changes in metallicity than to changes in age. In the optical, the Balmer lines are the best tracers of the MSTO temperature known. Although there is still some residual dependence of the MSTO temperature—and thus of the Balmer lines—on metallicity, Worthey (1994) showed that the equivalent single-burst (“SSP-equivalent”) age and metallicity of a stellar population can be read directly from two-dimensional diagrams of Balmer- and metal-line strengths (Fig. 2).
Figure 2. Central absorption-line strengths of early-type galaxies. (a) Field and group ellipticals (squares; González 1993) and S0’s (triangles; Fisher, Franx & Illingworth 1995). (b) Cluster early-types: Fornax (solid symbols; Kuntschner 1999) and Coma (open symbols; Jørgensen 1999).

3. The Stellar Populations of Early-Type Galaxies

Two-dimensional grids of Balmer- and metal-line strengths are shown in Figure 2 for local elliptical and S0 galaxies in the field and in groups (Fig. 2a) and in the Fornax and Coma clusters (Fig. 2b). It is immediately obvious that early-type galaxies are not uniformly old stellar populations varying primarily in metallicity. Even in dense clusters like Coma and Fornax, many S0 and even a few elliptical galaxies have SSP-equivalent ages of a few Gyr. (This behavior has even been seen in cluster populations at $z \sim 0.4–0.8$; Trager 1997; Trager, Faber & Dressler, in prep.) The distribution of stellar population parameters (age, metallicity, enhancement ratio—akin to [$\alpha$/Fe]—and iron abundance) for a sample of 39 early-type galaxies (and the bulge of M31) are shown in Figure 3 (Trager et al. 1999).

These SSP-equivalent ages are difficult to interpret directly, as line strengths of composite populations add like vectors weighted by the light of each population. Figure 4 shows this effect graphically: even a small burst of intermediate-age ($\sim 1$ Gyr old) populations dramatically increases the H$\beta$ strength of an old stellar population. For example, most elliptical galaxies in the field can be explained by a small (a few to 10% by mass) burst of a 1 Gyr population on top of a very old, very massive stellar population; a 10% burst by mass of a 1 Gyr old population on top of a 17 Gyr old population looks like a 2–3 Gyr old population (depending on the exact burst model chosen). In the most extreme

1Small amounts of blue straggler stars and very metal-poor populations contributing blue horizontal branch stars can also perturb the H$\beta$ strengths of early-type galaxies but cannot seriously affect the H$\beta$-strong galaxies seen Figure 2 (Trager et al. 1999).
cases (e.g., the field elliptical NGC 6702) the 1 Gyr old burst required is as much as 20% of the total stellar mass.

Note that burst strengths get much larger when the age of the burst population is constrained to be much older than 1 Gyr due to the rapidly increasing M/L ratio of old stellar populations with age. Burst ages much less than 1 Gyr are unlikely in most galaxies due to the lack of significant amounts of hot star light seen at 4000 Å (Rose 1985). In multiple burst scenarios (two or more bursts on top of an old population) the most recent burst, especially one that occurred less than 1.5 Gyr ago, will dominate the final line strengths.

4. Conclusions and Cautions

Local early-type galaxies in all environments, and even cluster S0 galaxies at redshifts out to at least $z \approx 0.8$ (Trager, Faber & Dressler, in prep.), show evidence for at least small amounts of recent star formation superimposed on old, massive progenitors. Typically these frostings of intermediate-age stars comprise a few to about 10% of the mass of the total stellar population, but some extreme cases may require up to 20% or more of the stellar population to have been formed 1–2 Gyr ago—i.e., at redshifts $z \lesssim 0.2$.

Although these bursts seem mild, even these mild starbursts will cause significant spectrophotometric—and possibly morphological, if these starbursts are dynamically induced—changes in the progenitors of today’s early-type galaxies at modest redshifts. For a starburst strength of 10% by mass in an early-type galaxy, Charlot & Silk (1994) have demonstrated that the colors require roughly a Gyr to revert to pre-burst levels (cf. Schweizer & Seitzer 1992). However,
Figure 4. The effects of multiple bursts on absorption-line strengths (Trager et al. 1999). Three models are shown, all consisting of fractional amounts (by mass) of 1 Gyr burst population superimposed on a 17 Gyr old progenitor population. Model A is meant to represent a plausible burst in a giant elliptical galaxy. The other two models are meant to represent plausible bursts in a small ($\sigma < 150 \text{ km s}^{-1}$) elliptical, one (model B) using solar abundance-ratio populations, the other (model C) involving a metal-enriched wind ([E/Fe] < 0) on top of a SN II-rich progenitor ([E/Fe] > 0). Bursts of 10%, 20%, 40%, 60%, and 80% by mass are shown as open squares; bursts of 50% by mass are shown as solid circles. Open squares are progenitor (lower) and burst (upper) populations. Solid squares are field ellipticals from González (1993), repeated from Figure 2.
the morphological evolution may be much quicker than that—Mihos (1995) has shown that a merger of two massive disk galaxies takes about a Gyr to relax back into an early-type morphology; 10% accretion events are unlikely to take that long. Because the amount of mass required by the burst increases strongly with the present age of the burst, these starbursts will become more dramatic with redshift (if only a single secondary burst occurs in each galaxy, a simplistic assumption). In any case, the spectrophotometric and possible morphological changes induced in even a mild burst will make identification of at least some of the progenitors of present-day elliptical galaxies a difficult task with photometric redshifts. This is just the “progenitor bias” (van Dokkum & Franx 1996): if the progenitors of some fraction of today’s early-type galaxies were not early-type galaxies at a given redshift, any sample of early-type galaxies at that redshift would consequently be biased towards the oldest galaxies. The progenitor bias does not affect the detection and identification of old early-type galaxies in photometric redshift surveys, but it does make the interpretation of the evolution of those galaxies more problematic.

Acknowledgments. I am grateful to my collaborators, Alan Dressler, Sandra Faber, Jesus González, and Guy Worthey for allowing me to present some of this material in advance of publication. I would also like to thank the organizers, Robert Brunner, Marcin Sawicki, Lisa Storrie-Lombardi, and Ray Weymann for an enjoyable (and convenient!) meeting.

References

Charlot, S. & Silk, J. 1994, ApJ, 432, 453
Faber, S. M. 1972, A&A, 20, 361
Faber, S. M. 1973, ApJ, 179, 731
Fisher, D., Franx, M., & Illingworth, G. 1995, ApJ, 448, 119
González, J. J. 1993, Ph.D. Thesis, UC Santa Cruz
Mihos, J. C. 1995, ApJ, 438, L75
O’Connell, R. W. 1980, ApJ, 236, 430
Renzini., A. 1986, in Spectral Evolution of Galaxies, eds. C. Chiosi & A. Renzini (Dordrecht: Kluwer), p. 151
Rose, J. A. 1985, AJ, 90, 1927
Schweizer, F. & Seitzer, P. 1992, AJ, 104, 1039
Trager, S. C. 1997, Ph.D. Thesis, UC Santa Cruz
Trager, S. C., Faber, S. M., González, J. J., & Worthey, G. 1999, AJ, submitted
VandenBerg, D. A. 1985, ApJS, 58, 711
van Dokkum, P. G. & Franx, M. 1996, MNRAS, 281, 985
Worthey, G. 1994, ApJS, 95, 107