Near-UV Merger Signatures in Early-Type Galaxies

Jodie R. Martin\textsuperscript{1}, Robert W. O’Connell\textsuperscript{2}, and J. E. Hibbard\textsuperscript{3}

\textsuperscript{1} University of Virginia, Charlottesville, VA \texttt{jodie@virginia.edu}
\textsuperscript{2} University of Virginia, Charlottesville, VA \texttt{rwo@virginia.edu}
\textsuperscript{3} National Radio Astronomy Observatory, Charlottesville, VA \texttt{jhibbard@nrao.edu}

**Summary.** Hierarchical assembly of early-type galaxies (Es and S0s) over an extended period of time will result in mixed-generation stellar populations. Here we look for signatures of composite populations in broad-band, near-ultraviolet (2500-3400 Å), high-resolution HST imaging of the cores of 12 bright early-type galaxies without obvious dust or active galactic nuclei. Near-UV imaging is a sensitive probe for the detection of younger components with ages in the range of 10 Myr to 5 Gyr. Only two galaxies have central colors ($r < 0.75 r_e$) that are consistent with a single-generation population. The other ten require a composite population.

1 Introduction

In $\Lambda$CDM cosmology galaxies are assembled hierarchically over an extended period by mergers of smaller systems. All galaxies, including early type galaxies (ETGs), are expected to contain multi-epoch stellar populations. Toomre & Toomre [17] were the first to suggest that some early types could form from the interactions of disk galaxies. They predicted that a dynamical redistribution of stars could transform merging disk galaxies into an elliptical galaxy, though such a redistribution of a collisionless system would not increase the maximum density to that observed in elliptical cores [9]. It was later realized that the gaseous components of the progenitor galaxies would collide, compress, and rapidly flow into the center of the gravitational potential well [6, 7, 16], where they can form new stars, thereby increasing the central density of the remnant.

There is considerable evidence supporting a merger origin for at least some fraction of the ETG population. Observations of the disk-disk merger remnant NGC7252 show a surface brightness profile as well as a maximum density similar to an elliptical galaxy, not to a disk galaxy [14]. Molecular gas densities in three merger remnants similarly indicate evolution toward an ETG remnant [4]. A study of the K-band light profiles of coalesced merger remnants found excess stellar light [12] in the centers of some of the galaxies. Monochromatic
photometric surveys of nearby ETGs [1, 10, 11] have serendipitously discovered that 20-40% have excess light above a smooth profile in the center-most regions, and many nearby ETGs show dynamical disturbances that correlate with color [15]. Finally, at higher redshifts ETGs with blue cores [5] and the E+A galaxies [2, 8] are likely post-merger systems.

If these central light excesses result from mergers, they are likely to contain intermediate-age stellar populations. In this project, we are using the Hubble Space Telescope (HST) to study that possibility by obtaining near-UV light profiles and colors of two groups of ETGs: a main sample with excess light in their centers and a control sample without. We emphasize the near-UV band because it is the most sensitive to intermediate-age stellar populations.

2 Sample Selection and Observations

Twelve galaxies were selected from published HST imaging studies of ETGs [1, 10, 11]. We chose six galaxies with light profiles that rise smoothly with decreasing radius and six with apparent excess light at small radii above a smooth profile. All twelve were chosen to have no known AGNs and no discernible central dust. The sample includes seven E’s, one dE, and four S0 galaxies.

The twelve galaxies were observed in Cycle 13 with HST using the ACS-HRC in three filters: F250W (“NUV”), F330W (“U”), and F555W (“V”). The exposure times were selected to achieve similar sensitivity levels across all bands. Each exposure was dithered in four positions per filter for sub-pixel sampling and cosmic ray cleaning. The pixel scale of the HRC is 0.027′′/pix with a 27′′ × 27′′ field of view and the full-width half maximum of the point spread function (PSF) is 0.0459′′ (1.7 pixels) for all three filters. Features larger than 2.5-6.1 parsecs in the sample galaxies are resolved.

3 Data Processing and Stellar Population Models

The images were initially processed and combined through the HST pipeline routines CALACS and Multidrizzle. Isophotes were fit to the V images and then applied to the U and NUV images to extract their light profiles; derived colors are therefore for annular elliptical apertures. Sky background estimates were made from two sources - an average over blank field exposures extracted from the HST archive, and an average over the outer 5 × 10^4 pixels of each galaxy image. The minimum of the two estimates was used. The observed images in each band were smoothed with the other two filters’ PSFs, since each PSF differs slightly in its substructure.

In this contribution, we discuss only the integrated colors of the galaxies. The total light within a radius of 0.75 r_e of the smoothed images was measured in each band, where r_e is the effective radius measured in the B-band[18]. The
colors were corrected for foreground reddening. The effect of the anomalous central component on integrated colors was checked by masking out the central 0.015 $r_e$ and remeasuring the fluxes. The deviations were less than 0.013 mag in both the NUV-V and U-V colors.

We use the Pégase stellar population synthesis models [3] to interpret the galaxy colors. Spectral energy distributions (SEDs) are available for a predetermined grid of ages, $\tau$, and metallicities, $Z$, in the form of monochromatic luminosities per unit mass, $[S]=(\text{erg/s/A}/M_\odot)$. These were computed for an instantaneous burst with a Salpeter initial mass function [13] over the mass range of 0.1 – 120 $M_\odot$. We select the subset of models that covers the age range of 10 Myr to 15 Gyr and the 3 highest metallicities, $Z=\{0.4,1,2.5\} Z_\odot$. The synthetic SEDs were integrated over the HST bandpasses to get total normalized luminosities for each age and metallicity.

To interpret our photometry, we compare the locations of the galaxy colors to the Pégase single-generation models and also to simple dual-generation models made up of an old population of age $\tau_O$ and a young population of age $\tau_Y$ that contributes a fraction of the total mass of the galaxy $f_Y$. We assume that the old and young populations have the same metallicity. Our grid of mixed models is computed as follows:

$$S_{\text{Mix}}(Z, \tau_Y, f_Y, \lambda) = f_Y \times S(Z, \tau_Y, \lambda) + (1 - f_Y) \times S(Z, \tau_O, \lambda)$$

where $f_Y$ evenly covers the log fraction space between $10^{-4}$ to $9 \times 10^{-1}$. Most of the models assume $\tau_O = 12$ Gyr. Note that a single-generation stellar population corresponds to the case $f_Y = 1$.

4 Results

Figures 1 and 2 compare the integrated galaxy colors to the single- and dual-generation stellar population models. In Figure 1, the single-generation models are plotted as open symbols connected by solid lines and the galaxies as solid diamonds and circles. The plot provides a consistency check on the photometry and the models in the sense that no objects lie significantly below or to the right of the single-generation model locus; this region is “forbidden” to composite populations. The locus corresponding to simple mixed-metallicity models — i.e. populations of a small age range (say 10-12 Gyr) but a large range of $Z$ — is narrow and closely follows the single-generation line.

In Figure 2, the single-generation populations are shown again along with tracks of dual-generation populations for a 12 Gyr old population and five younger components (10 Myr [solid lines], 100 Myr, 400 Myr, 1 Gyr, 4 Gyr [dashed lines]). The locus for the 10 Myr component represents an upper envelope to the region that is consistent with a dual-generation model for a given old population age. The sensitivity of the NUV to small amounts of light from young populations is indicated by the large volume of color-color space enclosed within the upper envelopes. In general, many dual-generation
models are consistent with a given data point in this region, but limits can be placed on their components.

Only two galaxies, NGC 3377 and NGC 3384, have colors which are consistent with single-generation populations, and these require $Z \gtrsim Z_{\odot}$. All of the other galaxies require mixed-generation populations. Eight of these require a dominant population with $Z > Z_{\odot}$, assuming no components can be older than 12 Gyr. The corresponding limit for NGC 4482 and NGC 4239 is $Z \gtrsim 0.5 Z_{\odot}$. To exemplify the stellar population mixture interpretations, we find 3 galaxies (NGCs 2778, 4478, and 4570) are well described by old, supersolar populations mixed with young components of ages 250, 500, and 450 Myr, and total mass contributions of 0.4, 1.5, and 1.2%, respectively.

Our basic result is that most of the galaxies show strong evidence of a composite population with contributions from components much younger than 10-12 Gyr. This is expected if most early type galaxies have formed by mergers over extended periods. Interestingly, this is true whether or not the galaxies possess excess central light suggestive of a late merger event (filled circles versus diamonds in Figs. 1 & 2). Although the three largest departures from the single generation locus occur for excess light systems (NGCs 4239, 4482, and 7457), the UV/optical color properties of the other members of the two groups are similar. The colors also show that, because the excess central light feature does not affect the total integrated colors, the new stars formed during a merger event are far more efficiently mixed throughout the merger remnant than the numerical models predict [6, 16].

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Fig. 1. Color-Color plot comparing the total integrated colors of the 12 galaxies to the single-generation single-metallicity Pégase models and the tracks of single-generation mixed-metallicity models for a few select ages, [1 Gyr, 4 Gyr, 12 Gyr].
Fig. 2. Color-Color plot comparing the total integrated colors of the 12 galaxies to the single-generation single-metallicity Pégase models and the tracks of dual-generation single-metallicity models for a few select ages, [+100 Myr, +400 Myr, +1 Gyr, +4 Gyr]. For each metallicity, the track for +10 Myr is shown as a solid line for emphasis.