Are early-type galaxies really "red and dead"?
New far UV observations of passive galaxies in the UVCANDELS survey

Tyler Hagen, Dr. Michael Rutkowski, and the UVCANDELS collaboration
Minnesota State University, Mankato, Department of Physics and Astronomy

Introduction

Galaxy formation from the first galaxies to today

In the low-redshift universe, galaxies typically belong to one of two major classes: Early-type (ETGs; massive with spheroidal morphologies and few young stars, i.e. "red and dead") and Late-type (less massive, but star-forming with disk morphologies) [1]. However in the early history of the universe, galaxies looked very different, with irregular morphologies, tremendous reservoirs of gas, and high rates of star formation. *These galaxies* ***must*** *have transformed into the local population of galaxies,* ***but how****?*

The formation of ETGs

Modern theories of ETG formation predict that they formed initially in the early universe as galaxies where the extant molecular gas was quickly (t<<1Gyr) consumed in a burst of intense star formation. This resulted in the heating and loss of the remaining gas, effectively "quenching" star formation [2]. Since that time, the massive galaxies "passively" evolved, i.e., they formed no new stars, and thus can be considered as progenitors of many present-day ETGs. However, this theory fails in one major respect: high redshift progenitors of compact present-day ETGs must grow significantly in size, while their mass remains approximately constant (Fig.1) [3]. Many theories attempt to explain this observed size growth [4,5,6], and one in particular invokes galaxy mergers to resolve the issue: these galaxies could periodically accrete low-mass satellite galaxies through gas-rich, minor mergers (i.e., $M_{passive}/M_{sat} >> 3$), which promotes size evolution more effectively than it does growth in mass [7].

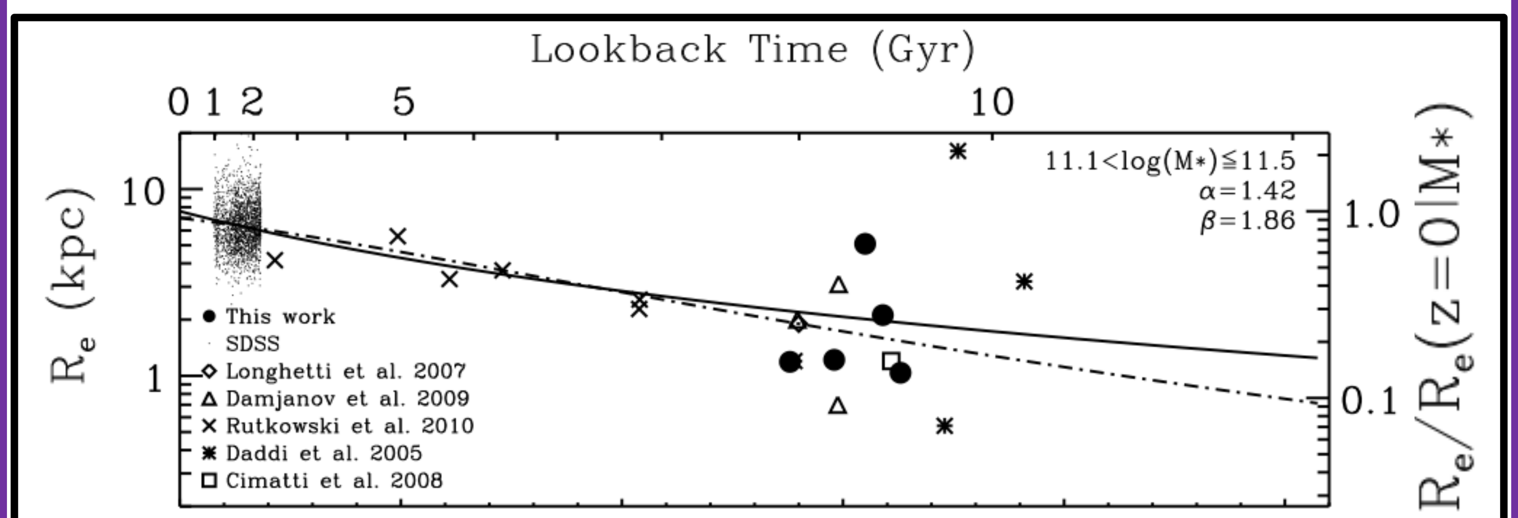

Fig. 1. The observed size-mass evolution of ETGs. For a fixed mass (M ~ 10^{11} $M_{\odot}$), ETGs are observed to grow, on average, by ~4x in radius since redshift z ~2 (see right vertical axis for reference with size normalized to the SDSS population) [3]. *Note no low-redshift analogs to the most compact massive galaxies are observed.*

Building a complete model of galaxy assembly

If the observed size-mass evolution can be partly explained by minor mergers, then in a sufficiently large, deep survey, 1) some massive, passive galaxies may be "caught in the act" of star formation as a result of the accretion of cold gas via satellites, and 2) these recently star-forming galaxies could be distinguished from the sample of truly passive galaxies by the richness (i.e., local density of satellites) of their environments. The UVCANDELS survey provides exactly the observational dataset necessary for testing this scenario. Covering the largest area ever surveyed with the HST, UVCANDELS provides deep WFC3/F275W (rest-frame far UV at z~1) imaging at high spatial resolution, which can be used to identify and characterize any young stars that may exist in these otherwise passive galaxies.

Sample Selection

We selected massive (M ≥ 10^{10} $M_{\odot}$) galaxies at intermediate redshift (0.5 ≤ z ≤ 1.5) in the GOODS-North field, using value-added 3D-HST survey catalogs [8]. Of these, we selected over 300 passive (or "quiescent") galaxies, applying a standard color criterion ("UVJ"; Fig. 2). We removed ~10 galaxies from this catalog that showed strong emission lines, suggesting highly dust-obscured star formation or the presence of an active galactic nuclei. We identified a sub-sample of ~60 quiescent galaxies observed in both 3DHST+CANDELS *and* in Epoch 1 UVCANDELS survey data. Note, we find 22 are detected (>3σ) in F275W, indicating the existence of low-level star formation. *Without UVCANDELS data, these galaxies—which will provide unique insight to the evolution of progenitors of ETGs—would be indistinguishable from the general population of z~1 quiescent galaxies.*

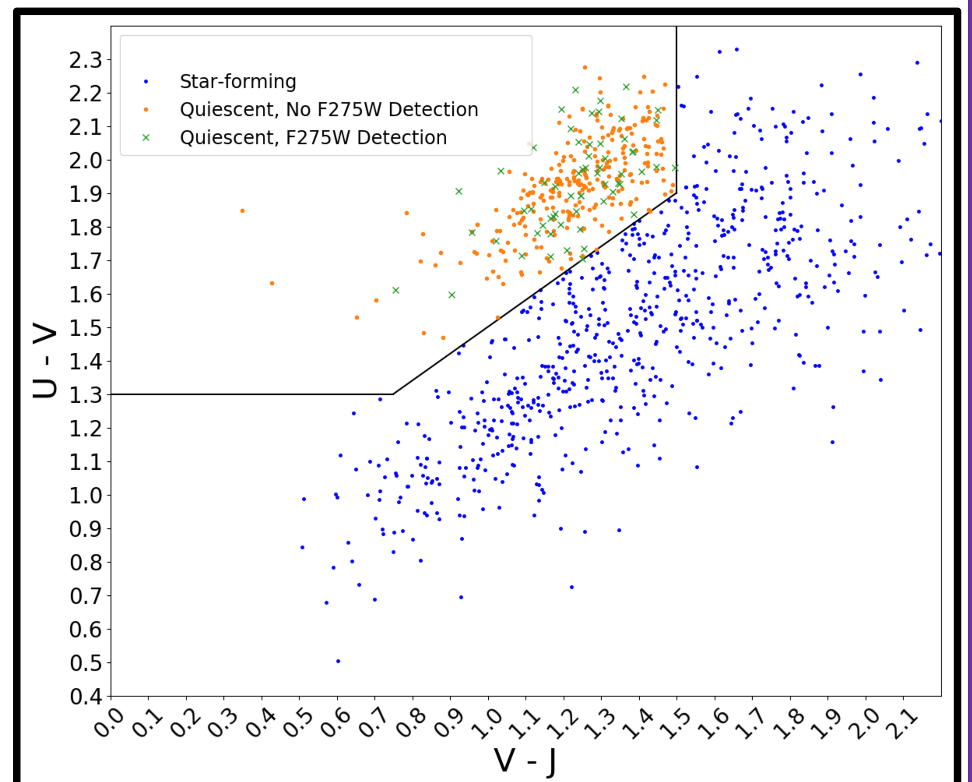

Fig. 2. Selection of passive galaxies. Plot of U–V versus V-J for each galaxy, where U, V, and J are measured magnitudes in the U, V, and J broadband filters respectively.

Optical Size Measurements

We applied a spatial light profile fitting software, known as GALFIT ([9]), to measure the size and shape of this sample. This popular software iteratively fits a wide range of structural parameters associated with common galaxy morphological models, measuring the best-fit model by a χ^2 minimization. In our initial analysis we considered only Sérsic models in the measurement of the galaxy 2D spatial light profiles. In this traditional model, the intensity of the stellar light profile is characterized by a decline in radius, r, as:

$$I(r) = I(0) \times \exp\left[-b_n (r/r_e)^{1/n}\right]$$

where $I(0)$ is the central intensity, b_n is a normalization constant, n is the Sérsic index (a measure of how quickly the stellar light decays with radius from the core), and r_e is the effective radius (radius within which half of the total light flux associated with the modeled profile is enclosed) [10]. The effective radius was used as a proxy for galaxy size in subsequent size-mass analysis, for models with $0.5 \lesssim \chi^2 \lesssim 3$.

Object	Reduced χ^2
J123608 +620832	0.623
J123603 +620951	1.11
J123607 +621517	1.17

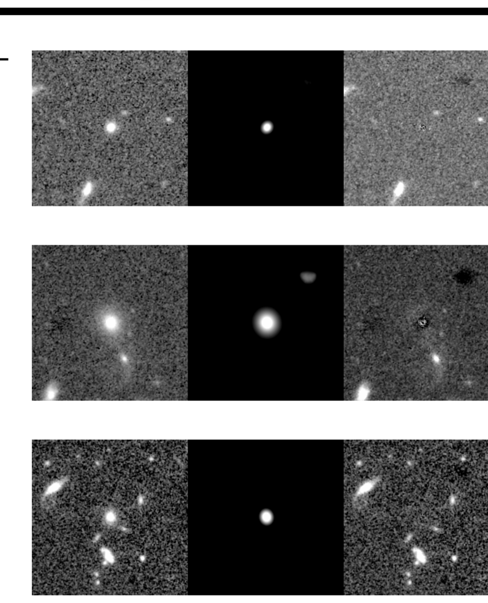

Fig. 3. Examples of GALFIT results for quiescent galaxies. From left to right, the columns displayed are as follows:
- *Far Left* - The galaxy name, produced using the galaxy coordinates (epoch: J2000);
- *Left* - The quiescent galaxy, imaged in the F125W broadband filter from CANDELS;
- *Center* - The best-fit GALFIT model, fitting only a single Sérsic profile with 1<n<10. The average Sérsic index for the sample is ~1.6, indicating that the light profiles of these galaxies are not uniformly bulge-dominated;
- *Right* - The residual map. This image is produced by differencing the input science image and the best-fit model;
- *Far Right* - The reduced χ^2 of each best-fit GALFIT model.

Results

We measured the size-mass distribution for the quiescent sample, using stellar masses from 3D-HST in combination with the best-fit effective radii estimated using GALFIT (Fig. 4). Here, only the most massive (M > $10^{10.5}$ $M_{\odot}$) and compact (r_e < 5 kpc) galaxies are shown. Overplotted (solid line) is the linear best-fit trend measured for these galaxies. For reference, we also reproduce the size-mass distribution of z~0 ETGs (dashed line) [11].

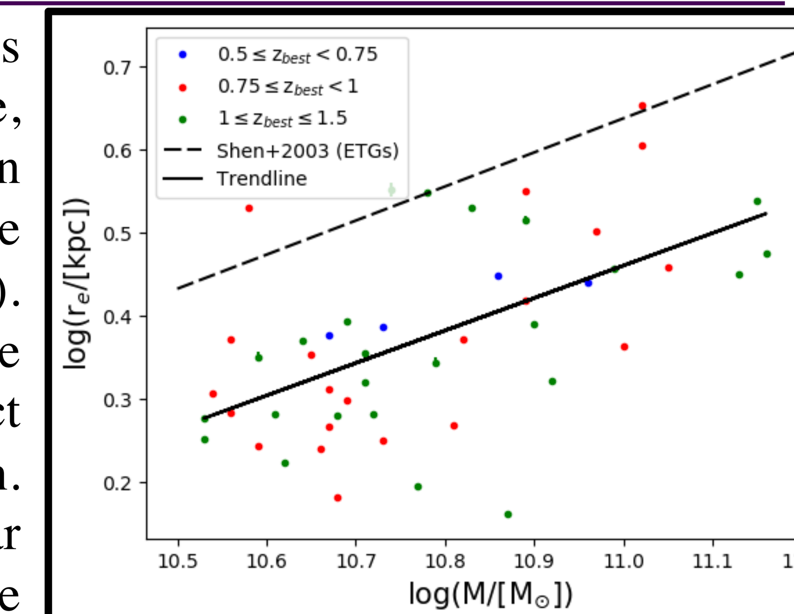

Fig. 4. Size-mass evolution. In good agreement with previous results, we measure a factor of ~2 increase in the size of the most compact passive galaxies between z~1 and the local population of z~0 (Shen+2003) [11].

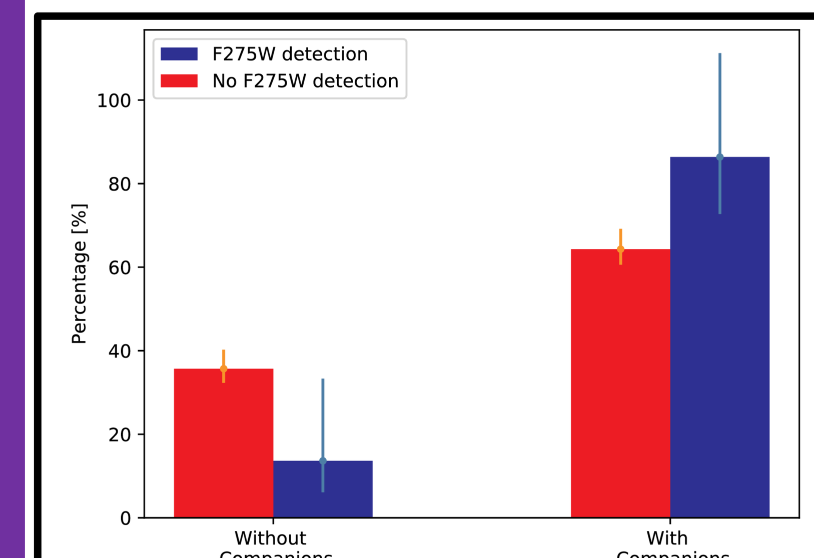

Fig. 5. The local environments. RSF galaxies appear in richer environments, *perhaps indicating a merger-driven origin for the observed size-mass evolution.*

We measured the relative number of companion galaxies for the quiescent sample, both those with and without F275W detection (Fig. 5). Here, we define a companion with respect to the host requiring:
1) Physical separation, r<~150kpc (i.e.,θ<25" at z~1)
2) Redshift separation, Δz<0.01.

Conclusions and Future Work

We have selected a large sample of massive, quiescent galaxies at intermediate redshift using HST imaging and spectroscopic surveys. We measured the size-mass relation and environment for the sample, and find:
- Of the galaxies that are imaged in UVCANDELS, ~1/3 have significant F275W detection (>3σ) and are likely to have recently formed (<100Myr) a minority (<<1%) of their stellar mass in a recent star formation episode, despite their identification as passive or "red and dead" galaxies [12];
- Compact, quiescent galaxies at z~1 are ~2x smaller than those at z = 0 (i.e. present day). Future UVCANDELS imaging will provide ~1000 additional galaxies for a robust measurement of this size-mass relation;
- Passive galaxies with F275W detection appear to be located in more densely populated environments, with comparatively more neighboring galaxies.

All three of these conclusions tentatively support a merger-driven size-mass evolution, in which quiescent galaxies may restart star formation post-merger.

In future work, we will fit additional models (e.g. multi-component Sérsic profiles) and a more refined point spread function to ensure robust size-mass measurements in advance of publication. In addition, we will fit the full multi-wavelength HST spectral energy distribution (SED) for each galaxy to derive the mass, age, and star formation history of the minority young stellar population identified for a fraction of these passive galaxies.

References

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