IMAGING OF THREE POSSIBLE LOW-REDSHIFT ANALOGS TO HIGH-REDSHIFT COMPACT RED GALAXIES

HSIN-YI SHIH AND ALAN STOCKTON

Institute for Astronomy, University of Hawaii, 2680 Woodlawn Dr, Honolulu, HI 96822, USA; hsshih@ifa.hawaii.edu, stockton@ifa.hawaii.edu

Received 2010 November 4; accepted 2011 March 4; published 2011 May 3

ABSTRACT

As part of a larger program to identify and characterize possible low-redshift analogs to massive compact red galaxies found at high redshift, we have examined the morphologies of three low-redshift compact galaxies drawn from the sample of Trujillo et al. Using deeper and higher resolution images, we have found faint and relatively extensive outer structures in addition to the compact cores identified in the earlier measurements. One object appears to have a small companion that may be involved in an ongoing minor merger of the sort that could be responsible for building up the outer parts of these galaxies. The ages of the dominant stellar populations in these objects are found to be around 2–4 Gyr, in good agreement with the previous estimates. The presence of diffuse outer structures in these galaxies indicates that truly compact and massive red galaxies are exceedingly rare at low redshift. The relatively young stellar populations suggest that the accretion of the extensive outer material must occur essentially universally on relatively short timescales of a few billion years or less. These results confirm and extend previous suggestions that the driving mechanism behind the size evolution of high-redshift compact galaxies cannot be highly stochastic processes such as major mergers, which would inevitably leave a non-negligible fraction of survivors at low redshift.

Key words: galaxies: evolution – galaxies: formation

Online-only material: color figure

1. INTRODUCTION

Morphologies of high-redshift galaxies are important in providing constraints on galaxy formation models. High-redshift massive galaxies showing little or no recent star formation have been found to be more compact than their lower-redshift counterparts of similar masses (e.g., Stockton et al. 2004; Daddi et al. 2005; Trujillo et al. 2007; Zirm et al. 2007; Toft et al. 2009; van Dokkum et al. 2008; Franz et al. 2008; Buitrago et al. 2008; Damjanov et al. 2009; Muzzin et al. 2009, and references therein) and many recent efforts have been made to understand their nature and subsequent evolution (e.g., Cimatti et al. 2008; Hopkins et al. 2009; van Dokkum et al. 2010; Wuyts et al. 2010). Kriek et al. (2006) have found that ~45% of the massive K-band-selected galaxies at z ~ 2.3 have old stellar populations. Van Dokkum et al. (2008), using high-resolution images of the Kriek et al. sample from Hubble Space Telescope and laser-guide-star adaptive-optics, estimated that ~90%-100% of these massive galaxies with old stellar populations are extremely compact, with mean effective radii of <1 kpc.

Such galaxies present an evolutionary puzzle, since they are not present or at least are exceedingly rare in the present-day universe. It has been suggested that these high-redshift compact galaxies might have evolved into present-day elliptical galaxies through “dry” mergers (Khochfar & Silk 2006) or “puffing up” due to quasar feedback (Fan et al. 2008), among other processes. However, as pointed out by Taylor et al. (2010), if the evolution involves purely stochastic processes such as mergers, some significant fraction of these galaxies is expected to survive intact and to be found in the lower-redshift universe. This possibility is of considerable interest because, at z > 2, these galaxies are quite faint, and since they have no emission lines, they are extremely difficult to study in any detail. As a consequence, some recent studies have focused on identifying and characterizing possible local analogs of these objects (e.g., Trujillo et al. 2009; Taylor et al. 2010; Stockton et al. 2010).

Trujillo et al. (2009, henceforth T09) searched the Sloan Digital Sky Survey (SDSS) DR6 NYU Value-Added Galaxy Catalog (Blanton et al. 2005) for nearby massive compact galaxies (z < 0.2, M > 8 × 10^10 M⊙, and (circularized) R_e < 1.5 kpc). From an original sample of 48 selected by their search criteria, they analyzed the SDSS data of 29 objects that were not impacted by nearby objects or rejected for other reasons. A search by Taylor et al. (2010) at a lower redshift (z < 0.12, with almost no overlap with the range of T09) of SDSS DR7 returned no candidates as massive and as compact as those identified at high redshift. In our own earlier study, Stockton et al. (2010), we found that truly small, massive, compact galaxies seem to be extremely rare even at a somewhat higher redshift. At this earlier epoch, but with a similar comoving volume to that of T09 (~200 deg^2 and 0.4 ≲ z ≲ 0.8), we found just two confirmed cases of compact massive galaxies. While we had somewhat more stringent selection criteria (effectively, M ≳ 2 × 10^11 M⊙ and R_e < 1.0 kpc), we still felt it important to check into the comparatively large number found by T09, particularly since the angular effective radii were comparable to, or smaller than, the SDSS pixel scale. To improve our understanding of the true morphologies of the objects in T09, we obtained deeper and higher resolution images for three of them using Keck I Low Resolution Imaging Spectrometer (LRIS; Oke et al. 1995).

2. OBSERVATIONS AND DATA REDUCTIONS

Out of the T09 sample, we chose the three galaxies accessible during our April observing run with apparent masses >10^{11} M⊙, SDSS J090324.19+022645.3, SDSS J092723.34+215604.8, and SDSS J101637.23+390203.6. This last galaxy, SDSSJ1016, is listed by T09 to be the most compact object in their sample (R_e = 0.88 kpc). We deliberately chose galaxies from the upper
end of the mass range of the T09 sample, as these are poten-
tially the most similar to the compact passive galaxies that have
so far been observed at $z > 2$, which typically have masses of
$\sim 2 \times 10^{11} M_\odot$ or more. We observed these three galaxies
on 2010 April 8 UT using the red side of LRIS on Keck I
telescope. The images were obtained using the $I$ filter, which
is centered on 7599 Å and has an FWHM of 1225 Å. These
parameters are very close to those for the SDSS $i$ filter, and
we accordingly have calibrated our images on the SDSS sys-
tem using unsaturated stars that have good SDSS magnitudes.
A total of three dithered images were obtained for each ob-
ject, each with an exposure time of 180 s for SDSSJ0903, and
60 s for SDSSJ0927 and SDSSJ1016. The image scale was
0''135 pixel$^{-1}$ (compared to 0''396 for the SDSS), and the
FWHM of the final images ranged from 0''52 to 0''67. The data
were reduced with IRAF following standard procedures for bias
subtraction and flat-fielding using dome flats, and the three
images for each galaxy were then registered and averaged. Surface
brightness (SB) limits for the final images ($3\sigma$) were estimated
from the variance of sky measurements in 4''8 apertures and
amounted to $i = 27.3$ for the SDSSJ0903 field and $i = 26.7$
for the SDSSJ0927 and SDSSJ1016 fields. These correspond to
about 2.2 and 1.6 mag fainter, respectively, than those measured
for the SDSSJ0903, which typically have masses
$z > 2$, which typically have masses of
$\sim 2 \times 10^{11} M_\odot$ or more. We observed these three galaxies
on 2010 April 8 UT using the red side of LRIS on Keck I
telescope. The images were obtained using the $I$ filter, which
is centered on 7599 Å and has an FWHM of 1225 Å. These
parameters are very close to those for the SDSS $i$ filter, and
we accordingly have calibrated our images on the SDSS sys-
tem using unsaturated stars that have good SDSS magnitudes.
A total of three dithered images were obtained for each ob-
ject, each with an exposure time of 180 s for SDSSJ0903, and
60 s for SDSSJ0927 and SDSSJ1016. The image scale was
0''135 pixel$^{-1}$ (compared to 0''396 for the SDSS), and the
FWHM of the final images ranged from 0''52 to 0''67. The data
were reduced with IRAF following standard procedures for bias
subtraction and flat-fielding using dome flats, and the three
images for each galaxy were then registered and averaged. Surface
brightness (SB) limits for the final images ($3\sigma$) were estimated
from the variance of sky measurements in 4''8 apertures and
amounted to $i = 27.3$ for the SDSSJ0903 field and $i = 26.7$
for the SDSSJ0927 and SDSSJ1016 fields. These correspond to
about 2.2 and 1.6 mag fainter, respectively, than those measured
for the SDSSJ0903, which typically have masses

3. DATA ANALYSIS AND RESULTS

We used Galfit (Peng et al. 2002), a two-dimensional galaxy
profile fitting routine, to determine some of the morphological
properties of our targets. Point-spread functions (PSFs) were
derived from unsaturated stars in the immediate fields of the
galaxies by using the stellar images themselves for the inner
part of the profile (down to 1%–2% of the peak), while
fitting the wings of the stars with two-component elliptical
Moffat profiles to eliminate sky noise. Because the galaxies
are resolved and turned out to be complex objects, we had to
fit two or three Sérsic components to each to get reasonably
low residuals when subtracting the model from the observed
image. Our goal in choosing the number of components to
use was to effectively eliminate large-scale systematic residuals
from the model subtractions. There was an additional problem
with SDSSJ0903, in that a ~0.4 radius region around the
center of the galaxy was either in the nonlinear CCD response
regime or saturated. This region was masked off for the fits
for SDSSJ0903, as were all discrete objects in the rest of
the field for all objects. The one exception was for SDSSJ1016,
where there is a companion too close to the galaxy for effective
masking. In this case, we simply included this object in the
fitting procedure, using a single Sérsic fit. The best-fit output
parameters from galfit are summarized in Table 1. Galfit
outputs the effective radius in units of pixels, and the physical
sizes were calculated using Ned Wright’s Javascript Cosmology
Calculator (Wright 2006) assuming a flat cosmology with
$H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$ and $\Omega_M = 0.27$ (these values differ
slightly from the $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$ and $\Omega_M = 0.3$ used
by T09; however, scale differences between the two amount to
only ~1% at the redshifts in question). While Galfit gives as the
effective radius the semimajor axis value $a$, the values given
for $R_e$ in Tables 1 and 2 are circularized (i.e., $R_e = a \times b/a$,
where $a$ is expressed in kpc). This convention ensures that half
of the total light of the model is within the elliptical isophote
that encloses an area of $\pi R_e^2$. The images of data, models,
and residuals of the best fits are shown in Figure 1. For comparison

| Object Name          | $z$ | $r_p$ (arcsec) | $R_e$ (kpc) | $n$ | $b/a$ | $m_I$ |
|----------------------|-----|----------------|-------------|-----|-------|------|
| SDSS J090324.19+022645.3 | 0.187 | 0.072 | 0.84 | 4.26 | 0.40 | 17.28 |
| SDSS J092723.34+215604.8 | 0.167 | 0.050 | 1.56 | 1.29 | 0.12 | 18.62 |
| Total, all components: |       | 0.067 | 2.08 | 0.56 | 0.30 | 20.65 |
| Total, all components: |       | 0.040 | 1.05 |     |     | 16.96 |
| SDSS J101637.23+390203.6 | 0.195 | 0.050 | 0.30 | 0.80 | 0.59 | 18.02 |
| SDSS J090324.19+022645.3 | 0.187 | 0.072 | 0.84 | 4.26 | 0.40 | 17.28 |
| Total, both components: |       | 0.077 | 1.23 |     |     | 16.78 |
| Notes. Galfit output parameters of the two- or three-component fits for each
target. Each of the lines for each object represents one Sérsic component.
Column 2: object redshift. Column 3: circularized effective radius in arcsec.
Column 4: circularized effective radius in kpc. Column 5: Sérsic index. Column
6: minor to major axis ratio. Column 7: integrated magnitude of the component.
For SDSSJ0903, the weak third component (accounting for only 3% of the total
light) has been offset 3′′ to the east from the center to model the asymmetry in
this object.

| Object Name          | $R_e$ (LRIS) | $R_e$ (SDSS) | $R_e$ (T09) | $n$ | $b/a$ | $m_I$ |
|----------------------|--------------|--------------|-------------|-----|-------|------|
| SDSS J090324.19+022645.3 | 1.54 | 1.02 | 1.40 | 1.99 | 0.32 | 17.11 |
| SDSS J092723.34+215604.8 | 1.26 | 1.18 | 1.42 | 5.46 | 0.26 | 16.71 |
| SDSS J101637.23+390203.6 | 2.35 | 1.77 | 0.88 | 6.39 | 0.71 | 17.20 |
| Notes. Column 2: circularized effective radius in kpc for the LRIS images.
Column 3: circularized effective radius in kpc determined from galfit
analysis of the SDSS $i$-band images. Column 4: effective radius quoted by T09, based
on Blanton et al. (2005). Columns 5–7: values of the Sérsic parameter $n$, the
axis ratio $b/a$, and the total $I$ mag. all from the fits to the LRIS images.

We traced the surface brightness (SB) profile of our targets
using the ellipse task in STSDAS. The radial-surface-brightness
profiles along the major axes of the models and data, calculated
from elliptical annuli sampling, are shown in Figure 2. The PAs
of the elliptical annuli were obtained from the single-component
Sérsic fits and were held fixed, along with the center of each
ellipse, for all measurements. The ellipticity, however, was al-
lowed to vary, particularly since the fits of necessity include convection with the PSF. The multi-component models typi-
cally remained well within 0.1 mag ($\Delta m_{I,\text{max}} < 0.1$) of the data out
to at least 15 kpc. The single-component fits are slightly worse,
but mostly still within 0.2 mag of the data. Note that, although
the multi-component fits appear to be very close to the single-
component fits in the one-dimensional plots, adding more com-
ponents significantly reduced the $\chi^2$ in the two-dimensional fits.
More importantly, systematic residuals, although still present,
are greatly reduced in the multi-component fits. The residuals
from the single-component fits are shown as insets in the right-
hand panels of Figure 1.
4. WHAT IS THE RELATION BETWEEN LUMINOUS COMPACT PASSIVE GALAXIES AT HIGH AND LOW REDSHIFTS?

Our single Sérsic fits returned $R_e$ comparable to values in T09 for SDSSJ0903 and SDSSJ0927. However, for SDSSJ1016, which had the smallest listed $R_e$ of their sample, our fits gave an $R_e$ that was almost three times as large as theirs. Our SB plots show that the single Sérsic profile fits the SDSSJ1016 data very well up to at least 6 kpc, so any significant decrease in the effective radius would certainly result in a much worse fit. We believe that this discrepancy is mostly resolved by our galfit measurement of the SDSS $i$-band image (which we carried out at the suggestion of the referee). This determination gives a value of $R_e$ twice that quoted by T09 from the Blanton et al. (2005) catalog, which apparently is in error for this galaxy. The remaining difference from our LRIS value may be due to the lower resolution and depth of the SDSS images. In Figure 1 we can see that SDSSJ1016 has an outer extended component that appears to have faded into noise in the shallower SDSS exposures, possibly accounting for the increased $R_e$ that we measured.

Single-component fits are fine for rough estimates of the galaxy morphologies and for comparison with other single-component fits, but we find that they leave rather large systematic residuals for all of our objects. By using more components for fitting, we were able to significantly reduce these residuals. For example, from the SB plot of SDSSJ1016, it is especially clear that the model deviates from the data beyond $\sim 7$ kpc. Adding a second component improved the fit to the outer regions of the galaxy. In these multi-component models, each galaxy has one component with $R_e < 1$ kpc comprising from 32% to 74% of the total light, with the remainder distributed in much more extended, low-surface-brightness components. Note that, although we have used three components in our models for SDSSJ0903 and SDSSJ0927, the offset third component in SDSSJ0903 is only present to model the asymmetry in the extended component of this galaxy, accounts for only $\sim 3\%$ of the total flux, and probably should not be considered to be a discrete physical entity. On the other hand, SDSSJ0927 appears to be a truly complex object, given that the three fitted components are nearly equally balanced in flux and that the two outer components have very different ellipticities. Nevertheless, it is still the case that all three galaxies fit the pattern of a compact ($R_e < 1$ kpc) core with a distinct more extended outer structure.

Both the single-component fits and the more complex structures of these low-redshift galaxies suggest that they are not as compact as most of those found at $z \sim 2.5$. While they may

![Figure 1](image-url) Images of the three galaxies. The first column shows the SDSS $i$-band images, the second column shows the LRIS images, the third column shows the galfit best-fit (multi-component) models, and the last column shows the residuals from subtracting the models from the images. The insets in the second and third columns show lower-contrast versions of the images and models, respectively. The insets in the last column show the residuals from the single-component fits. The image scale for all panels is shown at the lower right, and north is up and east to the left for all images.
have compact cores, they also have relatively extensive non-negligible wings that predominate in the outer regions. Wings having a similar SB relation to the cores would be visible within the dynamic range (typically \( \sim 5 \) mag; see, e.g., Stockton et al. 2008) accessible for at least some of the high-redshift galaxies. It is possible that these low-redshift objects are less massive compact galaxies that have acquired outer extended structures via some process such as accretion through minor mergers. SDSSJ1016 appears to have a small companion at the lower left of the data image in Figure 1, which we have had to include in our model to avoid distorting the fit to the main galaxy. If this smaller object is gravitationally bound to this system, it may be an example of this minor merging scenario in action. At least some massive compact galaxies found at intermediate redshifts also have a similar compact core + extended-component configuration on a smaller scale. The two \( \sim 0.5 \) objects studied by Stockton et al. (2010) each have a compact core with \( R_e \lesssim 250 \) pc containing \( \gtrsim 30\% \) of the light, and another larger component with \( R_e \sim 1.25 \) kpc (note that the original paper quotes semimajor axis values for \( R_e \), whereas we give circularized values here). T09 also estimated the average ages and metallicities of the stellar populations of the galaxies in their sample, using the \( \text{H} \beta \) and MgFe features in the Sloan spectra. They found that, compared with a carefully selected control sample of galaxies with similar masses and environments, but more typical values for \( R_e \), the compact galaxies had populations with significantly younger ages (\( \sim 2 \) Gyr versus \( \sim 14 \) Gyr) and somewhat higher metallicities (\( [Z/H] \sim 0.2 \) versus slightly less than solar). We have used a complementary approach of fitting Charlot–Bruzual spectral synthesis models (S. Charlot 2007, private communication\(^1\)) to the Sloan photometry. We have used models with a Chabrier initial mass function and explored metallicities of 0.4, 1.0, and 2.5 times solar, and after confirming that models with large amounts of extinction gave poor fits to the photometry, we modeled variations in \( A_V \) from 0.0 to 1.0, assuming a Calzetti et al. (2000) extinction law. We also tested both instantaneous bursts (i.e., forming all of the stars simultaneously) and more realistic models with exponentially declining star formation rates with \( e \)-folding times \( \tau \) of

\(^1\) These models are updated versions of those given by Bruzual & Charlot (2003), the main improvement being the incorporation of thermally pulsating asymptotic-giant-branch stars into the models.
up to 1.0 Gyr. For solar metallicity models, the model ages were 4.25, 3.75, and 4.0 Gyr with \( \tau = 0.5, 0.4, \) and 0.5 Gyr for SDSSJ0903, SDSSJ0927, and SDSSJ1016, respectively, all with \( A_V = 0 \). These solar metallicity models were the best fits for the first two, but a 2.5 times solar instantaneous burst model with an age of 1.68 Gyr and \( A_V = 0 \) gave a significantly better fit for SDSSJ1016. The stellar masses we obtain from our best-fit models (in units of \( 10^{11} M_\odot \)) are 1.7, 1.5, and 0.8, to be compared with values of 1.28, 1.28, and 1.08 given by T09. We thus have general agreement on both the fact that these galaxies are relatively young and on the stellar masses, and even some indication that some of the metallicities may be supersolar. These relatively young ages imply that the bulk of the stellar populations in these galaxies was formed at quite modest redshifts, ranging from \( \sim 0.4 \) to \( \sim 0.8 \).

Since all three of our targets appear to have larger diffuse components in addition to a more compact one, we suspect that many of the other galaxies in the T09 sample will also turn out to have these faint outer components. Deeper images of other objects in the T09 sample would easily determine whether most of them have structures as complex as the ones we have observed. These, as well as the two higher-redshift objects from Stockton et al. (2010), already appear to have undergone some evolution and are no longer purely compact objects. This result continues to suggest that truly small, massive, and compact galaxies similar to those common at high redshifts are extremely rare in the low-redshift universe. In addition, the best examples that have been found so far and studied in some detail seem not to be survivors from the population found at \( z > 2 \), but are instead fairly young objects, in the sense that the bulk of their stellar populations did not form at high redshifts. As emphasized by Taylor et al. (2010), the scarcity of truly old massive compact galaxies in the low-redshift universe cannot be explained by highly stochastic processes, such as major mergers. The driving mechanism behind the size evolution of the high-redshift population must operate in such a way that essentially all of them inevitably become incorporated into the sort of galaxies observed in the local universe. Furthermore, the relatively young ages of both the T09 sample and the massive compact galaxies we have studied at \( z \sim 0.5 \) (Stockton et al. 2010) indicate that this compactness is a stage that is, in cosmological terms, a rather brief one.

We can now attempt a broad-brush picture of some of the relevant points regarding these compact massive galaxies, along with some of the crucial unanswered questions.

1. Their compactness and implied mass densities indicate that they must have formed via strongly dissipative processes, most likely involving mergers of gas-rich systems (Khochfar & Silk 2006; Hopkins et al. 2010; Wuyts et al. 2010; Ricciardelli et al. 2010).

2. The very first massive galaxies seem to have formed in this way, given that almost all massive galaxies at \( z \gtrsim 2 \) that do not show continuing star formation are quite compact.

3. The comparative youth of the stellar populations in the T09 sample and in the two Stockton et al. (2010) galaxies suggests that these galaxies formed via mechanisms similar to those at high redshifts, but at later epochs. It would be of considerable interest to determine the mass fraction of very old (\( \gtrsim 10 \) Gyr) stars in these systems.

4. The compact massive galaxies found so far at low and intermediate redshifts all have significant extended components that are absent (at similar scaled surface brightnesses) from at least some of the high-redshift examples. There are at least two possibilities.

(a) After formation, the compact galaxies may acquire these components over timescales of \( \sim 2 \) billion years or so. This process may involve minor mergers or gas inflows, but, if so, the merger or inflow rate must be quite high. This conclusion follows from the observation that the absence or extreme rarity of “naked” compact massive galaxies at low redshift means that the extended components must be added via a fairly continuous rain of material rather than via a small number of discrete events. In addition, the total extended component mass involved in the cases studied so far ranges from several \( \times 10^{10} M_\odot \) to over \( \times 10^{11} M_\odot \), again suggesting a large amount of added material.

(b) The extended components could be the expected distribution of pre-existing stars in the galaxies whose merger precipitated the strong dissipation required to form the compact cores of these galaxies (e.g., Wuyts et al. 2010, and references therein). If so, we might expect that the stars in the these extended components might be somewhat older and of lower metallicity than the stars in the cores. Note that if the extended structures are actually disks that formed from the infall of new gas after the formation of the compact cores, the stellar populations would be younger than those of the cores. It would therefore be especially useful to obtain resolved spectroscopy of some of these galaxies to evaluate the nature of the stellar populations in the compact cores relative to those in the extended components.

Finally, our observation of SDSSJ1016 indicates the need to be cautious regarding some of the \( R_e \) values listed in the SDSS DR6 NYU Value-Added Galaxy Catalog (Blanton et al. 2005). While this catalog may be a good source for drawing up a list of candidate compact galaxies at low redshifts, it is clearly worthwhile to go back to the original SDSS images to check these candidates. Our initial skepticism about the feasibility of estimating \( R_e \) values from the relatively low-resolution SDSS images has proved to be too pessimistic, at least for galaxies with (single component) \( R_e \sim 1 \) kpc at \( z \sim 0.2 \). Nevertheless, even at \( z \sim 0.2 \), imaging observations with greater depth and finer pixel scale are useful for exploring the detailed structure of such galaxies, which is not apparent from the SDSS images.

We thank the anonymous referee for a careful reading of the paper and for making a number of detailed suggestions that greatly improved both its substance and its presentation. Funding for the Sloan Digital Sky Survey (SDSS) has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U. S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Korean Scientist Group, Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, University of Pittsburgh, University
of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

REFERENCES

Blanton, M. R., Schlegel, D. J., & Strauss, M. A. 2005, AJ, 126, 2562
Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000
Buitrago, F., Trujillo, I., Conselice, C. J., Bouwens, R. J., Dickinson, M., & Yan, H. 2008, ApJ, 687, L61
Calzetti, D., Armus, L., Bohlin, R. C., Kinney, A., Koornneef, J., & Storchi-Bergmann, T. 2000, ApJ, 533, 682
Cimatti, A., et al. 2008, A&A, 482, 21
Daddi, E., et al. 2005, ApJ, 626, 680
Damjanov, I., et al. 2009, ApJ, 695, 101
Fan, L., Lapi, A., De Zotti, G., & Danese, L. 2008, ApJ, 689, L101
Franx, M., van Dokkum, P. G., Förster Schreiber, N. M., Wuyts, S., Labbé, I., & Toft, S. 2008, ApJ, 688, 770
Hopkins, P. F., Bundy, K., Hernquist, L., Wuyts, S., & Cox, T. J. 2010, MNRAS, 401, 1099
Hopkins, P. F., Bundy, K., Murray, N., Quataert, E., Lauer, T. R., & Ma, C.-P. 2009, MNRAS, 398, 898
Khochfar, S., & Silk, J. 2006, ApJ, 648, L21
Kriek, M., et al. 2006, ApJ, 649, L71
Muzzin, A., van Dokkum, P., Franx, M., Marchesini, D., Kriek, M., & Labbé, I. 2009, ApJ, 706, L188
Oke, J. B., et al. 1995, PASP, 107, 375
Peng, C. Y., Ho, L. C., & Impey, C. D. 2002, AJ, 124, 266
Ricciardelli, E., Trujillo, I., Buitrago, F., & Conselice, C. G. 2010, MNRAS, 406, 230
Stockton, A., Canalizo, G., & Maihara, T. 2004, ApJ, 605, 37
Stockton, A., McGrath, E., Canalizo, G., Iye, M., & Maihara, T. 2008, ApJ, 672, 146
Stockton, A., Shih, H.-Y., & Larson, K. 2010, ApJ, 709, L58
Taylor, E. N., Franx, M., Glazebrook, K., Brinchmann, J., van der Wel, A., & van Dokkum, P. G. 2010, ApJ, 720, 723
Toft, S., Franx, M., van Dokkum, P., Förster Schreiber, N. M., Wuyts, S., & Marchesini, D. 2009, ApJ, 705, 255
Trujillo, I., Cenarro, A., de Lorenzo-Cáceres, A., Vazdekis, A., de la Rosa, I. G., & Cava, A. 2009, ApJ, 692, L118 (T09)
Trujillo, I., Conselice, C. J., Bundy, K., Cooper, M. C., Eisenhardt, P., & Ellis, R. S. 2007, MNRAS, 382, 109
van Dokkum, P. G., et al. 2008, ApJ, 677, L5
van Dokkum, P. G., et al. 2010, ApJ, 709, 1018
Wright, E. L. 2006, PASP, 118, 1711
Wuyts, S., et al. 2010, ApJ, 722, 1666
Zirm, A. W., et al. 2007, ApJ, 656, 66