THE ASTROPHYSICAL JOURNAL, 586:L45–L48, 2003 March 20

STELLAR MASSES OF LUMINOUS COMPACT BLUE GALAXIES AT REDSHIFTS $z = 0.4$–1.2

R. GUZMÁN,[1] G. ÖSTLIN,[2] D. KUNTH,[3] M. A. BERSHADY,[4] D. C. KOO,[5] AND M. A. PAHRE[6]
Received 2002 August 15; accepted 2003 February 5; published 2003 February 20

ABSTRACT

We present stellar mass measurements for a sample of 36 luminous compact blue galaxies (LCBGs) at redshifts $z = 0.4$–1.2 in the flanking fields around the Hubble Deep Field–North. The technique is based on fitting a two-component galaxy population model to multi-broadband photometry. Best-fit models are found to be largely independent of the assumed values for the initial mass function (IMF) and the metallicity of the stellar populations, but they are sensitive to the amount of extinction and the extinction law adopted. On average, the best-fit model corresponds to a LMC extinction law with $E(B-V) = 0.5$. Stellar mass estimates, however, are remarkably independent of the final model choice. Using a Salpeter IMF, the derived median stellar mass for this sample is $5 \times 10^9\ M_\odot$, i.e., ~2 times smaller than previous virial mass estimates. Despite uncertainties of a factor of 2–3, our results strengthen prior claims that L^* CBGs at intermediate redshifts are, on average, about 10 times less massive than a typical L^* galaxy today.

Subject headings: galaxies: evolution — galaxies: fundamental parameters — galaxies: photometry — galaxies: starburst — galaxies: stellar content

1. INTRODUCTION

Luminous compact blue galaxies (LCBGs) refers to a heterogeneous class of starburst systems with typical luminosities around L^* that become very common at intermediate redshifts (Koo et al. 1994, 1995; Guzmán et al. 1996, 1997; Phillips et al. 1997; Mallén-Ornelas et al. 1999; Hammer et al. 2001). LCBGs are particularly interesting for studies of galaxy formation and evolution since they have evolved more than any other galaxy class in the last ~8 Gyr (Mallén-Ornelas et al. 1999) and have been identified as a major contributor to the observed enhancement of the global star formation rate (SFR) density of the universe at $z \leq 1$ (Guzmán et al. 1997; Gruel 2002). Despite their cosmological importance, the nature of LCBGs and their relation to today's galaxy population still remain largely unknown. The most comprehensive study of LCBGs at intermediate redshift to date—only 45 objects—is that of Phillips et al. (1997) and Guzmán et al. (1997), who concluded that the LCBG class is populated by a mixture of starbursts. About ~60% of galaxies in their sample are classified as "H II–like" since they are spectroscopically similar to today's population of vigorously star-forming H II galaxies. The remaining ~40% are classified as "SB disk–like" since they are more evolved star-forming systems similar to local spiral galaxies, with a central starburst, and giant irregular galaxies.

Given the diverse nature of the LCBG population, they are unlikely to evolve into one homogeneous galaxy class. There are two popular scenarios. Koo et al. (1994) and Guzmán et al. (1996) have suggested that some subset of the most compact H II–type LCBGs at intermediate redshifts may be the progenitors of local low-mass spheroidal galaxies (or dwarf elliptical galaxies), such as NGC 205. Alternatively, Phillips et al. (1997) and Hammer et al. (2001) have suggested that SB disk–like LCBGs may actually be more massive disks forming from the center outward to become present-day L^* spiral galaxies. At the heart of this debate is the following question: Are the masses of LCBGs comparable to that of today's massive or low-mass galaxies? Prior measures of Keck velocity widths and *Hubble Space Telescope* sizes show that LCBGs have mass-to-light ratios that are only ~0.1–1.0 $M_\odot/L_{B,\odot}$, i.e., about 10 times smaller than a typical L^* galaxy today (Koo et al. 1994; Guzmán et al. 1996; Phillips et al. 1997). Since ionized gas emission-line widths may not reflect the true gravitational potential, an independent estimate of galaxy mass is desirable. Stellar mass is an obvious choice, since H I and CO emission-line widths are too difficult to measure in galaxies beyond the local universe.

Several authors have pointed out that the near-IR luminosity of a galaxy is a robust estimator of its stellar mass (e.g., Aragón-Salamanca et al. 1993; Alonso-Herrero et al. 1996; Charlot 1998). The main uncertainty in the inferred stellar masses arises from the age of the stellar population (Rix & Rieke 1993). Instead of using Hα to constrain the strength and age of a young burst (Gil de Paz et al. 2000; Östlin et al. 2001; Pérez-González et al. 2003a, 2003b), an alternative approach when studying galaxies at higher redshifts is to use rest-frame far-UV fluxes (Brinchmann & Ellis 2000, hereafter BE00; Papovich, Dickinson, & Ferguson 2001). Here we use a modified version of the method described in BE00 to estimate the stellar masses of a sample of LCBGs at intermediate redshift. Our goal is to test previous claims that LCBGs have, on average, an order-of-magnitude smaller masses than typical galaxies today with similar luminosities. In § 2, we introduce the photometric data set used in this analysis. In § 3, we describe the technique developed to derive stellar masses. The results are summarized in § 4. For consistency with previous work, throughout this Letter, we adopt $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.05$.

2. THE DATA

The initial galaxy sample consists of 40 LCBGs at redshifts $0.4 < z < 1.2$ selected from the flanking fields around the Hubble Deep Field–North, as described in Phillips et al. (1997). A wide

[1] Department of Astronomy, University of Florida, 216 Bryant Space Science Center, P.O. Box 112055, Gainesville, FL 326011-2055.

[2] Stockholm Observatory, Roslagstullsbacken 21, SE-106 91 Stockholm, Sweden

[3] Institute d'Astrophysique de Paris, 98 bis, Boulevard Arago, F-75014 Paris, France.

[4] Department of Astronomy, University of Wisconsin at Madison, 475 North Charter Street, Madison, WI 53706.

[5] University of California Observatories/Lick Observatory, Astronomy and Astrophysics Department, University of California at Santa Cruz, Santa Cruz, CA 95064.

[6] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.

TABLE 1
Grid of Model Spectral Energy Distributions

Parameter	Range
Age …………………	10^6–2×10^{10} yr in steps of 0.1 in log yr
SFR (burst) …………	Instantaneous and $\tau = 1.0$ Gyr
SFR (underlying) ……	$\tau = 1.0$ Gyr and constant
IMF …………………	Salpeter and Kennicutt
Metallicity …………	0.4 and 1 $Z_{\odot}$
$E(B-V)$ ……………	0.0, 0.25, 0.5, and 1.0 mag
Extinction law ………	MW, LMC, LMC-modified, SMC, and C94

variety of information for this sample was made publicly available by the Deep Evolutionary Extragalactic Probe collaboration, including F814W surface photometry, ($V_{F606W}-$F814W) colors, oxygen and Balmer emission-line equivalent widths, velocity widths, SFRs, and virial masses (Phillips et al. 1997; Guzmán et al. 1997). In addition, deep optical U_n, G, and R photometry for the entire Hubble Deep Field+flanking field area is available through the Caltech Faint Galaxy Redshift Survey (Hogg et al. 2000), while deep near-IR photometry in the notched HK' filter is listed in the Hawaii Flanking Field Catalog (Barger et al. 1999). After cross-correlating the various catalogs, we ended up with a final sample of 36 objects with deep U_n, G, R, F814W, and HK' photometry. Two-thirds of the objects are classified as H ii–like, while the remaining one-third are classified as SB disk–like. The limiting magnitudes for the photometry in each of these bands are $U_n = 25$, $G = 26$, $R = 25.5$, F814W = 25.0, and $HK' = 20.7$. As described in Phillips et al. (1997), all LCBGs in our sample are brighter than F814W = 23.74 mag, and their half-light radii are smaller than 0.″5. For F814W and HK', an estimate of the total magnitude was derived from the total flux within a 3″ diameter aperture. For U_n, G, and R, total magnitudes were derived after correcting the magnitudes within 1.″7 diameter apertures for flux outside the aperture considering the point-source case, as described in Hogg et al. (2000). The largest errors in the combined data set are due to the comparatively shallower near-IR data (typically $\sigma_{HK'} \sim 0.2$ mag).

3. STELLAR MASS ESTIMATES

The resulting photometric data set covers U_n through HK' in the observed frame. The red end of this range corresponds to ∼0.9 μm in the rest frame of the highest redshift considered here and to ∼1.3 μm for a more typical $z \sim 0.7$ galaxy in our sample. The blue end corresponds to a rest frame of ∼0.18 μm and of ∼0.23 μm, respectively. Gil de Paz & Madore (2002) have shown that this filter combination is well suited for deriving physical properties of galaxies at $z \sim 0.7$ from broadband data alone, including the star formation timescale, age, metallicity, and stellar mass.

Similar to the stellar mass estimates method described in BE00, we adopt a grid of evolutionary synthesis models with simple star formation histories (G. Bruzual & S. Charlot 2003, in preparation) and select the most appropriate evolutionary history by the error-weighted fitting of the optical and IR photometry. The models have three main parameters: initial mass function (IMF), SFR history, and metallicity. There are, however, some differences between our method and that described by BE00. First, instead of k-correcting the observed magnitudes for our LCBG sample, we chose to shift all model spectra to the redshift of each of our objects. Redshifted model spectra were convolved with the empirical filter functions corresponding to the actual U_n, G, R, F814W, and HK' broadband filters used in the observations to derive the model magnitudes. These magnitudes were then corrected for extinction by assuming not only a range of values for the color excess $E(B-V)$ a la BE00 but also a variety of extinction laws, including those derived for the Milky Way (MW; Mathis 1990), Large Magellanic Cloud (LMC; Bouchet et al. 1985), LMC with wavelength-dependent extinction correction (LMC-modified; Mas-Hesse & D. Kunth, private communication), Small Magellanic Cloud (SMC; Bouchet et al. 1985), and the so-called Calzetti's law (Calzetti, Kinney, & Storchi-Bergmann 1994, hereafter C94).

Second, there is growing evidence that LCBGs, both in the local and distant universe, have a composite stellar population that can be well represented by a young burst superposed on an older underlying population (Guzmán et al. 1998; Bergvall & Östlin 2001; Östlin et al. 2001; Gruel 2002). We use a composite "underlying+burst" model to fit the observed broadband magnitudes. The burst and underlying components are defined in terms of the assigned SFR histories, e.g., the instantaneous burst versus constant or exponentially decaying SFR. For simplicity, both populations are assumed to have the same IMF and metallicity. The best-fit model is found using a two-step, iterative procedure. First, a single burst model is fitted to the observed U_n, G, and R optical bands alone; i.e., the extinction-corrected model magnitudes are compared with the observed magnitudes, and the best fit is selected using a simple, weighted, least-squares minimization technique.[7] Weights were scaled with the flux in each band using the limiting magnitudes to provide the reference minimum weight. Since the observed U_n, G, and R bands map approximately the rest-frame UV region of the spectrum at the redshifts of our galaxies, light is entirely dominated by the youngest stars in the burst. The fitted model will provide an initial value for the age of the burst. Second, we fitted an underlying+burst model to all observed magnitudes, including F814W and HK'. The burst component is now restricted to vary by less than 10 time steps (or a factor of ∼2) in age from the initial value. Stellar masses are estimated by normalizing the combined underlying+burst spectral energy distribution to the observed magnitudes modulo the IMF. Table 1 summarizes the model ingredients.

Over 800 different model combinations were investigated. As shown by Gil de Paz & Madore (2002), the comparison of broadband photometry with the predictions of evolutionary synthesis models to derive galaxy physical properties yields, in general, highly degenerate results. A first set of "best-fit" models were selected on the basis of having the lowest residuals, i.e., the lowest standard deviations for the five differences between model and observed magnitudes.[8] The median residuals of the best-fit models are less than 0.15 mag. The largest median residuals are ∼0.35 mag, which correspond to models that use the MW extinction law with $E(B-V) = 1$. On this basis alone, we were

[7] No corrections for the nebular continuum were made to the U_n, G, and R magnitudes since its contribution is only significant for burst ages of a few times 10^6 yr, which are ruled out by the Hβ equivalent widths measured for our sample galaxies (Guzmán et al. 1997). The corrections for nebular line emission on these broadband magnitudes are estimated to be less than 10% (Bergvall & Östlin 2002) and were not applied.

[8] During the model fitting procedure, it was found that offsets needed to be applied to the observed magnitudes. We have not been able to identify the source of these offsets. They were derived iteratively as part of the fitting technique. Extensive Monte Carlo simulations were performed to ensure that our code could identify and recover artificially introduced zero-point offsets in fake galaxy catalogs that best mimic the properties of our LCBG sample. We are confident that the uncertainty in the derived stellar masses is dominated by model degeneracy and random photometric errors, as explained in the text, and not by offset errors, which contribute only 0.1–0.15 dex to the mass estimates.

able to reject the following cases: (1) models with constant SFR for the underlying component; (2) models with MW and LMC-modified extinction laws; and (3) models with LMC and SMC laws and $E(B-V) > 0.5$. The residuals were found to be only slightly dependent on the choice of IMF, metallicity, and star formation timescales. Since there is growing evidence that the IMF in star-forming and starburst regions is universal and consistent with Salpeter's (Leitherer 1998), we adopt a Salpeter IMF with lower and upper mass cutoffs of 0.08 and 125 $M_\odot$, respectively, for both the burst and underlying components. We also adopt a metallicity $Z = 0.4\ Z_\odot$, consistent with the range of metallicities observed in distant LCBGs (Guzmán et al. 1996; Kobulnicki & Zaritski 1999). Finally, we set the star formation timescales to be instantaneous for the burst and to be exponential with $\tau = 1$ Gyr for the underlying component.

The more restrictive choice of parameters reduces significantly the number of best-fit models. The solutions, however, are still degenerate since various combinations of $E(B-V)$, ranging from 0 to 0.5 mag, and extinction laws (LMC, SMC, and C94) all produce a low residual fit to the data. Since the timescales for the burst and underlying components in the models are now fixed, we find that the dominant source of degeneracy is the age-extinction degeneracy (Gil de Paz & Madore 2002). This is in the sense that an older burst with less dust extinction may yield as good a fit to the data as a younger but more extincted burst. If the burst is assumed to be less than 10^8 yr old, as suggested by the relatively strong [O II] λ3727 and Hβ equivalent widths (Guzmán et al. 1997), then we find only one best-fit model that fulfills all the conditions described in our analysis. According to this model, LCBGs are consistent with experiencing, on average, a 9% burst of star formation that is only 13 Myr old. This young component is superposed on an older, redder population that is, on average, 2 Gyr old. These results are qualitatively in good agreement with the burst strength and age estimates based on mass-to-light ratios and color analysis for a different sample of LCBGs (Guzmán et al. 1998). The derived amount of extinction, $E(B-V) = 0.5$ mag, is also in good agreement with the average value measured in starburst galaxies similar to LCBGs (Gil de Paz et al. 2000; Hammer et al. 2001; Rosa-González, Terlevich, & Terlevich 2002). We emphasize, however, that the results of the stellar mass measurements are remarkably independent of the final model choice, as it is discussed below.

Figure 1 shows the distribution of stellar masses for our LCBG sample. The median value of the overall distribution is $5 \times 10^9\ M_\odot$. This value is very similar to that derived for nearby LCBGs (Östlin et al. 2001). Note, however, that this value is about ∼10 times smaller than the average stellar mass in the sample of compact galaxies at intermediate redshifts by Hammer et al. (2001). This difference is most likely due to the intrinsic higher luminosity of their sample and the fact that these authors adopted a different *K*-band mass-to-light ratio. The median values for the H II–like and SB disk–like LCBGs are 5×10^9 and $2 \times 10^{10}\ M_\odot$, respectively. Although not significant in this small sample, these values suggest that SB disk–like LCBGs tend to be more massive than H II–like LCBGs. The mean value for the subsample of 17 LCBGs with blue luminosities around L^* (i.e., $M_B^* \pm 1$) is $(1.8 \pm 1) \times 10^{10}\ M_\odot$. This value is 1 order of magnitude lower than the stellar mass expected for a local L^* galaxy. Assuming $M_K^* = -25.1$ (for $H_0 = 50$ km s^{-1} Mpc^{-1}; Mobasher, Sharples, & Ellis 1993) and a *K*-band mass-to-light ratio of 1 $M_\odot/L_{K,\odot}$ (Héraudeau & Simien 1997), the estimated stellar mass is $2 \times 10^{11}\ M_\odot$. Thus, we conclude that the L^* CBGs at intermediate redshifts are about 10 times less massive than a typical L^* galaxy today. This result is in good agreement with previous claims based on virial mass estimates (Koo et al. 1994; Guzmán et al. 1996; Phillips et al. 1997). Our conclusion is not affected by the final choice of the model we adopted here. The median value for the stellar mass estimates derived from the other best-fit models differs by a factor of ∼2 from the median value given above. The highest values correspond to models using the C94 extinction law; these models yield a median stellar mass of $1.3 \times 10^{10}\ M_\odot$. We also note that a Salpeter IMF yields systematically higher masses, although only by 0.2 ± 0.05 dex. The use of a different IMF would strengthen our conclusion. Most interestingly, we find that LCBGs at intermediate redshifts span the same range of stellar masses and stellar mass-to-light ratios as that characteristic of Lyman break galaxies at redshifts $z \sim 3$ (Papovich et al. 2001).

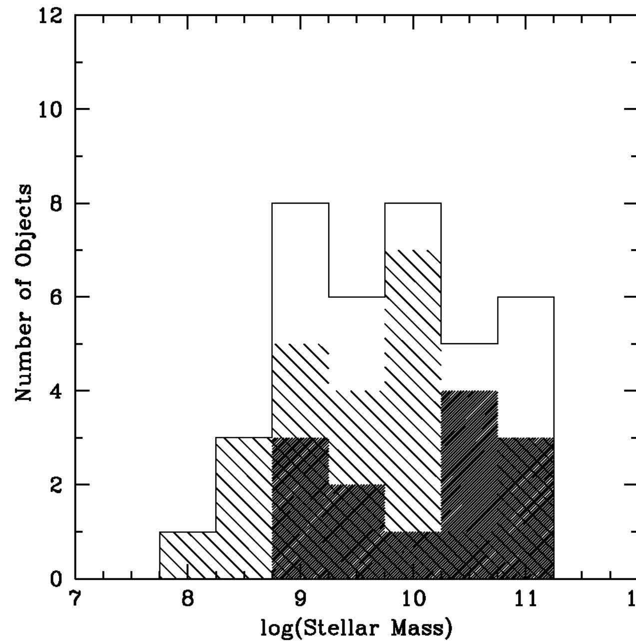

FIG. 1.—Histogram of stellar masses for our sample of LCBGs at intermediate redshift. *Solid histogram*: Distribution of stellar masses for the whole sample. *Gray histogram*: Distribution of stellar masses for SB disk–like LCBGs. *Hatched histogram*: Distribution of stellar masses for H II–like LCBGs.

Figure 2 shows the comparison of the stellar masses with the virial masses derived by Phillips et al. (1997). The virial masses used for this figure have been corrected for a systematic underestimate of the galaxy gravitational potential when emission-line velocity widths are used. This effect amounts to an ∼30% increase in observed velocity widths (Guzmán et al. 1996; Rix et al. 1997; Phillips et al. 1997; Pisano et al. 2001). No corrections for inclination were made. Rotationally supported, face-on LCBGs are likely to have virial masses significantly lower than their stellar masses. The 1 σ error bars have been calculated by propagating the magnitude errors, the standard deviations of the fit residuals, and the quoted errors in half-light radii and velocity widths. The largest source of uncertainty is associated with the errors in the shallower HK' photometry. The average error in the stellar mass measurements amounts to 0.36 dex (in log *M*). Excluding the two most uncertain measurements, the average of the estimated errors drops to 0.27 dex, i.e., a factor of ∼2. This value is comparable to the median error estimated by BE00 in their error analysis. The average random error for the virial mass measurements is estimated to be 0.18 dex. The median virial-

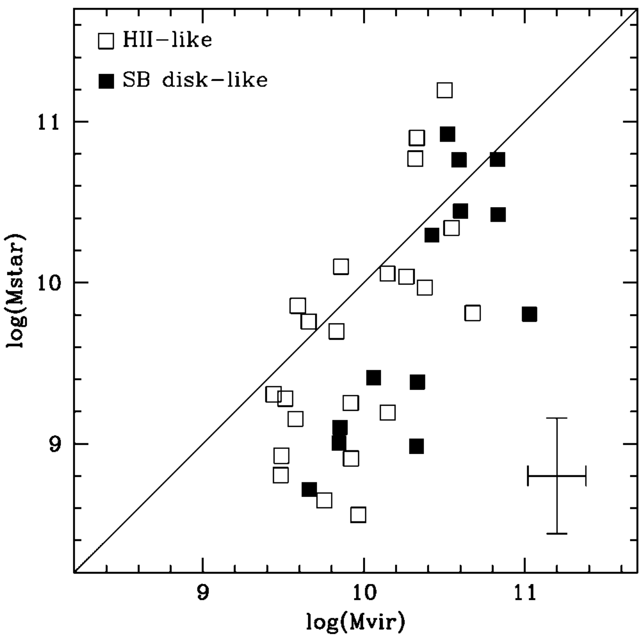

FIG. 2.—Virial mass vs. stellar mass for LCBGs in our sample in log $M_\odot$ units. *Open squares*: H II–like LCBGs; *filled squares*: SB disk–like LCBGs. The error bars correspond to average 1 σ errors.

to-stellar mass ratio is 0.39 dex. Thus, the stellar mass estimates of LCBGs are, on average, ∼2 times smaller than the virial mass estimates. This result is also in good agreement with the comparison between stellar masses and dynamical masses made by BE00 and Papovich et al. (2001). The scatter in the virial-to-stellar mass ratio is slightly larger than expected from the error analysis, although the exclusion of the two most deviant points results in 0.54 dex or a scatter of a factor of ∼3. No systematic differences in the virial-to-stellar mass ratios are detected between the SB disk–like and H II–like LCBGs. We note, however, that Figure 2 suggests a trend in the sense that the lowest stellar mass LCBGs tend to have the highest virial-to-stellar mass ratios.

4. CONCLUSIONS

We have presented a new method for determining robust stellar masses for LCBGs up to redshifts $z \sim 1.2$. Our method expands on previous work in the field by including a two-component burst+underlying model population fitted to a combination of rest-frame UV, optical, and near-IR broadband photometry in an iterative fashion. Although specifically tailored for starburst galaxies with a composite stellar population, this method can also be used to estimate the stellar masses of the field galaxies, in general, of known redshift. According to our best-fit model, LCBGs at intermediate redshifts can be described, on average, as starburst systems that are undergoing a 13 Myr old burst involving 9% of the galaxy mass superposed on an underlying, older population (2 Gyr). This model requires a modest amount of extinction [$E(B-V) = 0.5$], with a LMC extinction law. We have demonstrated via comparisons and simulations that the stellar masses can be estimated with a precision of log $\Delta M_{\rm star} \sim 0.3$ dex and that they are not significantly affected by the main assumptions needed to constrain the degeneracy intrinsic to this method. The median stellar mass for LCBGs in our sample is $5 \times 10^9\ M_\odot$, or ∼2.5 times smaller than previous mass estimates based on the virial theorem using scale lengths and emission-line velocity widths. The new, independent mass estimates are consistent with previous claims that L* CBGs at intermediate redshifts are about 10 times less massive than a typical L* galaxy today.

R. G. is grateful to the Institut d'Astrophysique de Paris and the Laboratoire d'Astrophysique at the Observatoire Midi-Pyrenee for their hospitality and financial support for this project. R. G. also acknowledges funding from NASA grants HF01092.01-97A and LTSA NAG5-11635. G. Ö. acknowledges support from the Swedish Natural Sciences Research Council and the STINT foundation. We thank Roser Pelló for providing the *k*-corrections used for an independent test of the quality of the photometric data and Jean-Michel Désert for helping in the cross-correlation of the various catalogs.

REFERENCES

Alonso-Herrero, A., Aragón-Salamanca, A., Zamorano, J., & Rego, M. 1996, MNRAS, 278, 417
Aragón-Salamanca, A., Ellis, R. S., Couch, W. J., & Carter, D. 1993, MNRAS, 262, 764
Barger, A. J., Cowie, L. L., Trentham, N., Fulton, E., Hu, E. M., Songaila, A., & Hall, D. 1999, AJ, 117, 102
Bergvall, N., & Östlin, G. 2002, A&A, 390, 891
Bouchet, P., Lequeux, J., Maurice, E., Prevot, L., & Prevot-Burnichon, M. L. 1985, A&A, 149, 330
Brinchmann, J., & Ellis, R. S. 2000, ApJ, 536, L77 (BE00)
Calzetti, D., Kinney, A. L., & Storchi-Bergmann, T. 1994, ApJ, 429, 582 (C94)
Charlot, S. 1998, in AIP Conf. Proc. 408, The Ultraviolet Universe at Low and High Redshift: Probing the Progress of Galaxy Evolution, W. H. Waller, M. N. Fanelli, J. E. Hollis, & A. C. Danks (New York: AIP), 403
Gil de Paz, A., Aragón-Salamanca, A., Gallego, J., Alonso-Herrero, A., Zamorano, J., & Kauffmann, G. 2000, MNRAS, 316, 357
Gil de Paz, A., & Madore, B. F. 2002, AJ, 123, 1864
Gruel, N. 2002, Ph.D. thesis, Obs. Paris
Guzmán, R., Gallego, J., Koo, D. C., Phillips, A. C., Lowenthal, J. D., Faber, S. M., Illingworth, G. D., & Vogt, N. P. 1997, ApJ, 489, 559
Guzmán, R., Koo, D. C., Faber, S. M., Illingworth, G. D., Takamiya, M., Kron, R., & Bershady, M. A. 1996, ApJ, 460, L5
Guzmán, R., Koo, D. C., Jangren, A., Bershady, M., Faber, S. M., & Illingworth, G. D. 1998, ApJ, 495, L13
Hammer, F., Gruel, N., Thuan, T. X., Flores, H., & Infante, L. 2001, ApJ, 550, 570
Héraudeau, P., & Simien, F. 1997, A&A, 326, 897
Hogg, D. W., et al. 2000, ApJS, 127, 1
Kobulnicky, H. D., & Zaritsky, D. 1999, ApJ, 511, 118
Koo, D. C., Bershady, M. A., Wirth, G. D., Stanford, S. A., & Majewski, S. R. 1994, ApJ, 427, L9
Koo, D. C., Guzmán, R., Faber, S. M., Illingworth, G. D., Bershady, M. A., Kron, R., & Takamiya, M. 1995, ApJ, 440, L49
Leitherer, C. 1998, in ASP Conf. Ser. 142, The Stellar Initial Mass Function: 38th Herstmonceux Conf., ed. G. Gilmore & D. Howell (San Francisco: ASP), 61
Mallén-Ornelas, G., Lilly, S. J., Crampton, D., & Schade, D. 1999, ApJ, 518, L83
Mathis, J. S. 1990, ARA&A, 28, 37
Mobasher, B., Sharples, R. M., & Ellis, R. S. 1993, MNRAS, 263, 560
Östlin, G., Amram, P., Bergvall, N., Masegosa, J., Boulesteix, J., & Márquez, I. 2001, A&A, 374, 800
Papovich, C., Dickinson, M., & Ferguson, H. P. 2001, ApJ, 559, 620
Pérez-González, P. G., Gil de Paz, A., Zamorano, J., Gallego, J., Alonso-Herrero, A., & Aragón-Salamanca, A. 2003a, MNRAS, 338, 508
———. 2003b, MNRAS, 338, 525
Phillips, A. C., Guzmán, R., Gallego, J., Koo, D. C., Lowenthal, J. D., Vogt, N. P., Faber, S. M., & Illingworth, G. D. 1997, ApJ, 489, 543
Pisano, D. J., Kobulnicky, H. D., Guzmán, R., Gallego, J., & Bershady, M. A. 2001, AJ, 122, 1194
Rix, H. W., Guhathakurta, P., Colles, M., & Ing, K. 1997, MNRAS, 285, 779
Rix, H. W., & Rieke, M. J. 1993, ApJ, 418, 123
Rosa-González, D., Terlevich, E., & Terlevich, R. 2002, MNRAS, 332, 283