THE METALLICITY OF 0.5 < z < 1 FIELD GALAXIES

C. Marcella Carollo
Columbia University, Department of Astronomy, Mail Code 5246, Pupin Hall, 550 West 120th Street, New York, NY 10027

and

Simon J. Lilly
University of Toronto, Department of Astronomy, St. George Campus, 60 St. George Street, Toronto, ON M5S 3H8, Canada;
and Herzberg Institute of Astrophysics, 5071 West Saanich Road, Victoria, BC V9E 2E7, Canada

Received 2000 October 9; accepted 2000 December 12; published 2001 February 19

ABSTRACT

We have measured the emission-line ratios in a sample of 34 Canada-France Redshift Survey star-forming galaxies with redshifts in the range of 0.5 < z < 1.0, and we have computed their metallicities by means of the empirically calibrated R23-metallicity estimator introduced by Pagel et al. The current analysis concentrates on the 15 galaxies with L(Hα) > 1.2 × 10^41 erg s⁻¹. Although our results can only be regarded as preliminary until near-IR spectroscopy of Hα and [N II] λ6583 are available, the metallicities of these galaxies appear to be remarkably similar to those of local galaxies selected in the same way, and there appears to have been little change in the relationship between metallicity and line and continuum luminosity from z ~ 1 to today. At this stage, our results do not support the idea that these galaxies, known to be generally small and with late-type morphologies, are dwarf galaxies brightened by large bursts of star formation, as had been suggested from previous studies. Rather, our findings are more consistent with a picture in which these systems are the progenitors of today’s massive metal-rich galaxies.

Subject headings: galaxies: abundances — galaxies: evolution — galaxies: formation

1 INTRODUCTION

There is now clear evidence from the Canada-France Redshift Survey (CFRS; Lilly et al. 1995b) and other similar surveys for evolutionary changes in the field galaxy population over the redshift interval 0 < z < 1 manifested as an increased number of blue galaxies, with a rest frame of (U-V)AB ≤ 1.4, and moderate luminosities, L ~ L*. The redshift regime 0.5 < z < 1.0 appears to be an important epoch in the history of the galaxy population. Evolutionary effects are clearly seen in the galaxy population, and the apparent change of behavior in the ultraviolet luminosity density of the universe as a whole at around z ~ 1 (Lilly et al. 1996; Madau et al. 1996; Steidel et al. 1999) may indicate that this epoch represents a transition between the “high-redshift” universe at z > 1 and that seen today. While the large galaxies appear to be absent at z ~ 2, large spiral galaxies and early-type galaxies are present at z ~ 0.8 in numbers comparable to those seen locally, coexisting with increased numbers of comparably bright but smaller irregular galaxies (Brinchmann et al. 1998, hereafter B98; Lilly et al. 1998, hereafter L98). There is morphological evidence for substantially elevated levels of merger activity at this epoch (Le Fèvre et al. 2000).

To date, much of the work on the z ~ 1 field galaxy population has been based on gross statistical measures such as the bivariate color-luminosity function (Lilly et al. 1995c; Heyl et al. 1997; Lin et al. 1999). The Hubble Space Telescope (HST) studies of the morphologies and sizes of field galaxies in redshift fields in this regime (e.g., B98; L98), and of the internal kinematics of various subsets of these galaxies (Vogt et al. 1997; Guzmán et al. 1997; Mallén-Ornelas et al. 1999), suggest that the most massive galaxies are evolving relatively slowly (Vogt et al. 1997; L98) while the “excess” galaxies in the luminosity function (with L ~ L* and blue colors) generally have the irregular morphologies (B98), small sizes (3–5 h⁻¹ Mpc; L98), and low-velocity dispersions (σ < 100 km s⁻¹; Guzmán et al. 1997; Mallén-Ornelas et al. 1999) that are usually associated in the local universe with galaxies 2–3 mag farther down the luminosity function. This suggests, at first sight, quite a strong luminosity brightening in late-type low-mass galaxies.

However, there are still major gaps in our knowledge of galaxies in the crucial 0.5 < z < 1.0 redshift regime that make it possible that this interpretation of the morphologies and the kinematic data is incorrect. Not least, the possibility that the small blue irregular galaxies are the cores of more massive galaxies—i.e., the “downsizing” scenario of Cowie et al. (1996)—cannot be ruled out at this stage. For example, the K-band luminosities of typical blue galaxies at z ~ 0.8 are comparable to those of today’s massive galaxies, leading to suggestions that at least some of these blue objects may indeed be the progenitors of massive systems.

There has hitherto been almost no systematic study in the 0.5 < z < 1 regime of the physical diagnostics that are familiar from studies of the local universe. For local galaxies, combinations of strong emission lines are routinely used to determine or constrain the nature of the ionizing radiation (Veilleux & Osterbrock 1987), the amount of reddening, and the metallicity of the interstellar medium (ISM; Pagel et al. 1979; Kennicutt 1998; Stiavelli 1998; Kobulnicky, Kennicutt, & Pizagno 1999). Although a rigorous determination of the ISM metallicity requires knowledge of the electron temperature derivable only from intrinsically weak lines, diagnostic line ratios based on stronger lines have been empirically calibrated. In particular, the R23-metallicity parameter, R23 = [O III] λ3727 + [O III] λλ(4959 + 5007)/Hβ (Pagel et al. 1979), has been empirically calibrated against metallicity, with an intrinsic scatter of only 0.2 dex. It is a weak function of the ionization ratio [O III] λλ(4959 + 5007)/[O II] λλ3727. A reversal in R23 occurs at Z ~ 0.3 Z⊙ because of cooling effects, so a low-metallicity and a high-metallicity solution are associated with most values of R23.
However, this degeneracy can be broken using the [O III] λ5007/[N II] λ6584 ratio (Kobulnicky et al. 1999). Based on data of relatively low redshift galaxies, Kobulnicky et al. (1999) have discussed in detail the potential accuracy that could be obtained in using \( R_{23} \) to measure metallicities of unresolved galaxies at high redshifts. These authors examined theoretically the effects of dust reddening, of H\( \beta \) absorption, of spatial averaging over extended galaxies with abundance gradients, and the possible effects of diffuse interstellar gas and provided prescriptions for dealing with these effects.

Determining the metallicity of the ISM of distant star-forming field galaxies is of particular importance, both as a general indicator of the evolutionary state of these systems and as a constraint on their possible present-day descendants. Some work has been done to determine the metal content of galaxies at redshifts of about 0.1 < \( z \) < 0.5 (Kobulnicky & Zaritsky 1999); however, no information has been available about the ISM metallicities of galaxies in the 0.5 < \( z \) < 1.0 redshift interval. Therefore, we have begun a program of systematic emission-line spectroscopy of CFRS galaxies in order to determine the ISM metallicity of 0.5 < \( z \) < 1.0 field galaxies and to study how the metal content in these systems correlates with galaxy luminosity, star formation rate, structure, and morphology. Our program uses the \( R_{23} \)-metallicity estimator and therefore requires spectroscopy of the [O III] \( \lambda \lambda 3727, 5007, \) and H\( \beta \) lines, which, in this redshift range, are shifted into the 5000 Å–1 \( \mu \)m wavelength region. Supplementary spectroscopy of He\( \alpha \), [N II] \( \lambda \lambda 6584, 6548 \), and [S II] \( \lambda \lambda 6717, 6731 \) lines, which are shifted into the near-infrared \( \lambda \) band, allows us to determine the reddening, the isolation of active galactic nuclei (AGNs), and the breaking of the \( R_{23} \)-degeneracy with metallicity.

In this Letter, we report the first results of our program; these results are based on deep multiobject spectrophotometry over the 0.5 < \( \lambda \) < 1.0 \( \mu \)m range. Infrared spectrophotometry has already been acquired for one object and will be obtained in due course for the remaining galaxies, but the optical data on their own already provide a set of homogeneous data that can immediately be compared at a phenomenological level with the equivalent local sample (see, e.g., Jansen et al. 2000).

Throughout this Letter, we use \( H_0 = 50 \) Mpc km s\(^{-1}\) s\(^{-1}\) and \( q_0 = 0.5 \), and we refer to solar metallicity \( Z_\odot \) as 12 + log (O/H) = 8.9.

2. SAMPLE SELECTION, OBSERVATIONS, AND DATA REDUCTION

The observations were carried out on the nights of 2000 March 5–7 at the 3.6 m Canada-France-Hawaii Telescope using the multiobject spectrograph (Le Fèvre et al. 1994) with the STIS-2 CCD detector with 21 \( \mu \)m pixels. A red-blazed grating with 300 line mm\(^{-1}\) and a short-wavelength cutoff filter yielded spectra between 5000 Å and 1 \( \mu \)m, and about 20 objects were observed on each multislit mask with slits 20′ long and 1′3 wide, giving a spectral resolution of \( R \sim 600 \). One mask was observed in each of the CFRS-10 and CFRS-14 fields (Le Fèvre et al. 1995; Lilly et al. 1995a).

Spectroscopy at \( \lambda \geq 7600 \) Å is challenging on account of the OH forest. The most important factors that hamper accurate spectroscopic measurements are sky subtraction and fringe removal. The use of relatively long slitlets (∼20′) and nine 2700 s exposures allowed us to offset the target galaxies along the slit at each integration and thus to eliminate, to a large extent, the defects in the sky subtraction that are fixed relative to the chip (e.g., those arising from chip fringing, imperfections in the slit profile, and distortions introduced by the spectrograph camera). The spectra were reduced with standard IRAF routines and calibrated via observations of two spectrophotometric standards. The spectra were corrected for (small) air-mass effects but not for Galactic reddening, since this is small \( (E_{B-V} < 0.03; \) Burstein & Heiles 1982). Comparisons of the spectra of standard stars observed through different slits in the masks indicated that the relative spectrophotometric calibration over the wavelength range of interest was about 10% (rms). However, the uncertainties in the relative line flux measurements were usually dominated by systematic uncertainties in establishing the local continuum, and these were conservatively estimated by exploring rather extreme possibilities. The errors in the line ratios were derived from adding in quadrature these two sources of uncertainty. In several cases, the strength of [O III] \( \lambda 4959 \) was only poorly estimated, and in these cases, the strength of this line was assumed to be 2.85 times that of [O III] \( \lambda 5007 \). In a few cases, the H\( \beta \) and/or [O III] \( \lambda 5007 \) were not convincingly seen in the spectra; for these galaxies, conservative upper limits were estimated through comparison with nearby features in the spectra that were known to be unreal.

The 34 target galaxies were selected from the CFRS to have, in addition to the original \( I_{AB} < 22.5 \) photometric selection, an [O III] \( \lambda 3727 \) flux in excess of \( 7 \times 10^{-17} \) ergs s\(^{-1}\) cm\(^{-2}\) in order to ensure strong enough lines for a measurement of the \( R_{23} \) parameter. The observational noise in the \( R_{23} \)-measurement is usually dominated by the uncertainty in the strength of H\( \beta \) that appears in the denominator of \( R_{23} \). The H\( \beta \) luminosity is likely to be closely related to the star formation rate and represents an astrophysically useful reference to galaxies in the local universe. Unfortunately, H\( \beta \) measurements were not available beforehand for most of the target galaxies because of the long-wavelength cutoff (at about 8400 Å) of the original CFRS spectra. A close approximation to an H\( \beta \) luminosity–selected sample can only be constructed a posteriori. The analysis presented in this Letter is based on the 15 objects—about 50% of the original [O III] \( \lambda 3727 \)-selected sample observed during the run—with H\( \beta \) luminosities above \( L_{H\beta} > 1.2 \times 10^{41} \) ergs s\(^{-1}\). It should be noted that any objects missing from such a sample would have low [O III] \( \lambda 3727/H\beta \) ratios and thus generally low \( R_{23} \)-values that generally correspond to high metallicities. This high-\( L_{H\beta} \) selection well samples the “blue” CFRS galaxy population with a rest frame of \( (U-V)_{AB} \approx 1.4 \) (Table 1). Two of the highest redshift galaxies, at redshifts \( z = 0.8718 \) and 0.9203, respectively, have easily detectable [Ne III] \( \lambda \lambda 3869, 5007 \) ratios.

On the log ([Ne III] \( \lambda 3869/H\beta \)) versus log ([O III] \( \lambda 3727/H\beta \)) plane of Rola et al. (1997), these systems (unlike the other 13) occupy locations typical of the local AGN population. Therefore, although they are formally part of our high-\( L_{H\beta} \) Sample, these probable AGNs will be distinguished in our comparison with the local galaxies. The remaining 13 high-\( L_{H\beta} \) objects span the redshift range 0.6 < \( z \) < 1 with a median redshift \( z = 0.783 \).

Three high-redshift galaxies in the original sample of 34 had upper limits to their H\( \beta \) luminosities that were above our \( L_{H\beta} = 1.2 \times 10^{41} \) ergs s\(^{-1}\) threshold, possibly putting these systems into the high-\( L_{H\beta} \) subsample that is discussed in this Letter. The line ratios for these galaxies are necessarily uncertain; however, we have included these systems in the figures for completeness and assigned to them the range of line ratios that they would have if their H\( \beta \) luminosities were indeed above our threshold. We have, however, identified these three objects with different symbols, as a reminder that they may actually not belong to the high-\( L_{H\beta} \) subsample. We report in Table 1 the relevant parameters for the 15 \( L_{H\beta} > 1.2 \times 10^{41} \) ergs s\(^{-1}\)
At the reversal of occurs, and the curves dashed lines are lines of constant metallicity. From left to right, by a flux ratio of \( [\text{O}^\text{ii}] \). Furthermore, in the left panel of Figure 1, the filled circles with smaller \( H_L \) were selected from the CfA redshift catalog (Huchra et al. 1983) sample, respectively. The galaxies of the Jansen et al. (2000) and the high-CFRS galaxies of our sample appropriately, in Figure 3, two probable AGNs are again excluded, there are no high- \( H_L \) objects at high redshifts (at least in this still small sample) that may or may not be in the sample on account of their \( H_L \) upper limits (open squares). The fiducial dotted-line box in both panels encompasses the bulk of the Jansen et al. galaxies. The arrows on the right side of the figures represent the direction in which the points of the diagram would shift as a result of reddening by dust (as described by Cardelli, Clayton, & Mathis 1989); the length of the arrows refers to \( E(B-V) = 0.3 \) mag at \( z = 0.7 \). The effects of reddening are a function of the \( [\text{O}^\text{ii}] \) \( \lambda 5007/[\text{O}^\text{iii}] \lambda 3727 \) ratio.

Several things are apparent in Figure 1. First, the high-redshift galaxies fall in the \( R_3 \) versus \( [\text{O}^\text{ii}] [\text{O}^\text{iii}] \) plane in locations that are occupied by galaxies in the local Jansen et al. (2000) sample. Furthermore, once the AGNs are excluded, the high-redshift sample selected to have \( L_{H_L} > 1.2 \times 10^{41} \) ergs s\(^{-1}\) occupies the same restricted location in the \( R_3 \) versus \( [\text{O}^\text{ii}] [\text{O}^\text{iii}] \) plane as do the objects in the local universe with similarly high \( H_L \) luminosities. At both epochs, galaxies selected to have the same \( H_L \) luminosities exhibit the same range of \( R_3 \) and \( [\text{O}^\text{ii}] [\text{O}^\text{iii}] \). (We note that there may possibly be a small displacement of the high-redshift galaxies toward the upper edge of the dotted box in the left panel of Figure 1. This could conceivably be due to the effects of higher dust extinction at high redshifts; it would be premature to claim this at this stage.)

It is also apparent in the right panel of Figure 1 that one of the two probable AGNs are again excluded, there are no high- \( L_{H_L} \) objects at high redshifts (at least in this still small sample) that have \( R_3 \sim 7 \), the value that is nondegeneratively associated with intermediate metallicities, i.e., \( Z \sim 0.3 Z_\odot \). The \( Z \)-degenerate \( R_3 \)-values that are measured for the high-\( z \), high- \( L_{H_L} \) galaxies indicate either rather low \(( \leq 0.1 Z_\odot ) \) or rather high \(( \sim 1 Z_\odot ) \) metallicities for these systems. Again, this is similar to what is observed in the local sample: high- \( L_{H_L} \) galaxies avoid the intermediate-metallicity regime both at the present and at the \( z \sim 1 \) epoch.

The similarity between the high- and low-redshift samples is further illustrated in Figure 2, which shows the relationship between \( R_3 \) and the continuum luminosity \( M_B \). There is a rather startling similarity between the high-\( z \) and local galaxies on this diagram. There is little evidence for an evolutionary change in the relationship between metallicity (as estimated from

### TABLE 1

| CFRS ID      | \( M_B \) (mag) | \( z \) | \( (V-I)_{\text{obs}} \) | \( (U-V)_{\text{rest}} \) | \( \log R_3 \) | \( \log ([\text{O}^\text{iii}] \lambda 5007/[\text{O}^\text{ii}] \lambda 3727) \) |
|--------------|----------------|-------|--------------------------|---------------------------|---------------|--------------------------------------------------|
| 10.0494      | −21.22         | 0.920 | 0.66                     | 0.41                      | 1.38          | (−0.5)                                            |
| 10.1213      | −20.94         | 0.815 | 1.27                     | 0.97                      | 0.47          | (−0.29/+0.38)                                     |
| 10.1925      | −21.00         | 0.783 | 1.00                     | 0.62                      | 0.51          | (0.12)                                            |
| (10.2164)    | −22.64         | 0.859 | 2.95                     | 2.48                      | 0.08          | (−0.5)                                            |
| (10.2183)    | −21.87         | 0.910 | 1.14                     | 1.56                      | 0.56          | (−0.5)                                            |
| 10.2418      | −22.00         | 0.796 | 2.39                     | 2.01                      | 0.19          | (−0.27/+0.24)                                     |
| 10.2428      | −21.23         | 0.872 | 1.78                     | 1.30                      | 0.83          | (0.07)                                            |
| 14.0217      | −20.94         | 0.721 | 1.00                     | 0.64                      | 0.56          | (−0.09/+0.10)                                     |
| 14.0272      | −21.98         | 0.670 | 1.19                     | 0.92                      | 0.09          | (−0.25/+0.29)                                     |
| 14.0394      | −21.85         | 0.603 | 0.98                     | 0.72                      | 0.45          | (−0.11/+0.12)                                     |
| 14.0438      | −22.12         | 0.988 | 0.74                     | 0.51                      | 0.47          | (0.10)                                            |
| (14.0497)    | −21.22         | 0.800 | 1.10                     | 0.73                      | 0.19          | (−0.14)                                           |
| 14.0538      | −21.18         | 0.677 | 0.57                     | 0.20                      | 0.70          | (0.07)                                            |
| 14.0605      | −20.69         | 0.837 | 0.40                     | 0.10                      | 0.62          | (0.09)                                            |
| 14.0818      | −22.27         | 0.901 | 1.12                     | 0.83                      | 0.47          | (0.17)                                            |
| 14.0972      | −21.37         | 0.810 | 0.82                     | 0.43                      | 0.62          | (0.05)                                            |
| 14.1258      | −20.14         | 0.647 | 0.97                     | 0.65                      | 0.54          | (0.07)                                            |
| 14.1386      | −21.46         | 0.744 | 1.05                     | 0.69                      | 0.25          | (−0.14/+0.15)                                     |

Note.—The three upper-limit objects are enclosed in parentheses in the first column, which lists the CFRS identification number (Lilly et al. 1995a; Le Fèvre et al. 1995). The remaining columns list, respectively, the absolute \( B \) magnitude, the redshift, the observed \( V−I \) and rest-frame \( U−V \) colors (AB magnitudes; from Lilly et al. 1995c), the \( R_3 \)-parameter, and the \( \log ([\text{O}^\text{iii}] \lambda 5007/[\text{O}^\text{ii}] \lambda 3727) \) ratio. In the last two columns, the positive numbers in parentheses are the error bars on the reported measurements (single-valued entries refer to symmetric errors); the negative numbers in parentheses indicate that the reported values are limits (lower ones for \( [\text{O}^\text{ii}] \lambda 5007/[\text{O}^\text{ii}] \lambda 3727 \), upper ones for \( R_3 \)).
Fig. 1.—The [O iii] λ5007/[O ii] λ3727 vs. \( R_{23} \) relation for the local field sample of Jansen et al. (2000; left panel) and the \( L_{\text{H}\beta} > 1.2 \times 10^{41} \) ergs s\(^{-1} \) CFRS galaxies of our sample (right panel). The symbols are explained in the text. The 0.5 < \( z < 1 \) galaxies with \( L_{\text{H}\beta} > 1.2 \times 10^{41} \) ergs s\(^{-1} \) appear to have metallicities as high as the equivalent high-\( L_{\text{H}\beta} \) objects in the local universe.

Fig. 2.—\( R_{23} \) vs. absolute \( B \) magnitude relation for the galaxies in the local universe (circles) and those in the 0.5 < \( z < 1 \) redshift regime (squares and asterisks). The symbols are the same as in Fig. 1 and are explained in the text. Above the \( L_{\text{H}\beta} > 1.2 \times 10^{41} \) ergs s\(^{-1} \) cutoff, the distribution of points for the local and high-\( z \) galaxy populations is identical.

\( R_{23} \), and the line and continuum luminosities for high-\( L_{\text{H}\beta} \) field galaxies between \( z \sim 0 \) and \( z \sim 0.8 \). This extends to higher redshifts the findings of Kobulnicky & Zaritsky (1999), which are based on a sample at 0.1 < \( z < 0.5 \).

For one of the non-AGN galaxies, CFRS-14.0393, we have already obtained a Keck spectrum in the \( J \) band and analyzed it to derive the intensity of the [N ii] λ6584 emission line. We will report the details on this analysis elsewhere. The important fact, relevant to the current discussion, is that the [O iii] λ5007/ [N ii] λ6584 ratio that this \( J \)-band spectrum has allowed us to measure for this (\( z = 0.6035 \)) object undoubtedly places it on the high-metallicity branch of the \( R_{23} \)-parameter, with a metallicity quite close to the solar value. This one case argues in favor of a high solar metallicity for at least some objects in our 0.5 < \( z < 1 \) high-\( L_{\text{H}\beta} \) sample. The \( HST \) morphology of this object is that of a regular two-armed spiral (Schade et al. 1995), and therefore it is not surprising that this galaxy has a possible high metallicity. It may be that our high-\( L_{\text{H}\beta} \) selection favors large, well-formed galaxies relative to the general blue CFRS population. However, there is no indication that this is the case from the \( HST \) morphology of three additional objects for which the \( HST \) data are available (CFRS-10.1213, CFRS-14.0972, and CFRS-14.1258).

Of course, until we obtain the infrared spectroscopy for the entire sample, the \( R_{23} \)-degeneracy with \( Z \) does not allow us to prove on what branch—i.e., the low- or high-metallicity one—each individual high-\( z \) galaxy lies, and the possibility remains that some objects have indeed metallicities \( Z \lesssim 0.1 \) \( Z_\odot \). However, at this stage, the absence of any galaxies with \( Z \sim 0.3 \) \( Z_\odot \) makes this possibility rather contrived, since it would imply a bimodal distribution of metallicities with a “gap” around such intermediate values of \( Z \). Therefore, although confirmation must await the infrared spectroscopy, the best working hypothesis seems the one in which all of the analyzed high-\( L_{\text{H}\beta} \) high-redshift galaxies have relatively high metallicities, i.e., within 40% of solar.

The consequences of these findings are interesting in the context of the studies of the sizes, morphologies, and kinematics of the high-redshift galaxies discussed above. In fact, it is clear that at this stage, the metallicity measurements of 0.5 < \( z < 1 \) systems do not support the idea that many of the small and irregular blue \( L^* \) galaxies responsible for the evolution of the luminosity function back to \( z \sim 0.8 \) and that dominate the CFRS at these redshifts (B98; L98) are low-mass (i.e.,
low-metallicity) dwarfs brightened by substantial luminosity evolution. In contrast, the metallicity data seem to suggest the interesting possibility that these small irregular galaxies are in fact the progenitors of today’s massive metal-rich galaxies, but seen in an earlier phase of their evolution when they were already significantly metal-rich but morphologically more disturbed and smaller. Although about one-third of the CFRS has been imaged by HST (see Schade et al 1995; B98), the overlap with this spectroscopic sample is as yet still small. Testing this idea by studying the morphologies of these metal-rich systems will have important consequences for our understanding of the evolutionary path of massive galaxies.

We thank Marijn Franx, Jules Halpern, Nino Panagia, and Massimo Stiavelli for helpful discussions. S. J. L.’s research in Toronto is supported by the Natural Sciences and Engineering Research Council of Canada and by the Canadian Institute for Advanced Research, and this support is gratefully acknowledged.

REFERENCES

Brinchmann, J., et al. 1998, ApJ, 499, 112 (B98)
Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Cowie, L. L., Songaila, A., Hu, E. M., & Cohen, J. G. 1996, AJ, 112, 839
Edmunds, M. G., & Pagel, B. E. J. 1984, MNRAS, 211, 507
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
Heyl, J., Colless, M., Ellis, R. S., & Broadhurst, T. 1997, MNRAS, 285, 613
Huchra, J. P., Davis, M., Latham, D., & Tonry, J. 1983, ApJS, 52, 89
Jansen, R. A., Fabricant, D., Franx, M., & Caldwell, N. 2000, ApJS, 126, 331
Kennicutt, R. C., Jr. 1998, in Proc. 34th Liège Int. Astrophys. Colloq., The Next Generation Space Telescope: Science Drivers and Technological Changes, ed. B. Kaldeich-Schürmann, P. Benvenuti, & P. Madau (ESA SP-429; Noordwijk: ESA), 81
Kobulnicky, H. A., Kennicutt, R. C., Jr., & Pizagno, J. L. 1999, ApJ, 514, 544
Kobulnicky, H. A., & Zaritsky, D. 1999, ApJ, 511, 118
Le Fèvre, O., et al. 2000, MNRAS, 311, 565
Le Fèvre, O., Crampton, D., Pelenbok, P., & Monnet, G. 1994, A&A, 282, 325
Le Fèvre, O., Crampton, D., Lilly, S. J., Hammer, F., & Tresse, L. 1995, ApJ, 455, 60
Lilly, S. J., Hammer, F., Le Fèvre, O., & Crampton, D. 1995a, ApJ, 455, 75
Lilly, S. J., Le Fèvre, O., Crampton, D., Hammer, F., & Tresse, L. 1995b, ApJ, 455, 50
Lilly, S. J., Le Fèvre, O., Hammer, F., & Crampton, D. 1996, ApJ, 460, L1
Lilly, S. L., et al. 1998, ApJ, 500, 75 (L98)
Lilly, S. J., Tresse, L., Hammer, F., Crampton, D., & Le Fèvre, O. 1995c, ApJ, 455, 108
Lin, H., Yee, H. K. C., Carlberg, R. G., Morris, S. L., Sawicki, M., Patton, D. R., Wirth, G., & Shepherd, C. W. 1999, ApJ, 518, 533
Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., & Fruchter, A. 1996, MNRAS, 283, 1388
Mallén-Ornelas, G., Lilly, S. J., Crampton, D., & Schade, D. 1999, ApJ, 518, L83
Pagel, B. E. J., Edmunds, M. G., Blackwell, D. E., Chun, M. S., & Smith, G. 1979, MNRAS, 189, 95
Rola, C. S., Terlevich, E., & Terlevich, S. R. 1997, MNRAS, 289, 419
Schade, D., Lilly, S. J., Crampton, D., Hammer, F., & Tresse, L. 1995, ApJ, 451, L1
Steidel, C. C., Adelberger, K. L., Giavalisco, M., Dickinson, M., & Pettini, M. 1999, ApJ, 519, 1
Stiavelli, M. 1998, in Proc. 34th Liège Int. Astrophys. Colloq., The Next Generation Space Telescope: Science Drivers and Technological Changes, ed. B. Kaldeich-Schürmann, P. Benvenuti, & P. Madau (ESA SP-429; Noordwijk: ESA), 71
Veilleux, S., & Osterbrock, D. E. 1987, ApJS, 63, 295
Vogt, N., et al. 1997, ApJ, 479, L121