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LYMAN-α EMISSION IN STAR-FORMING GALAXIES[1]

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ABSTRACT

We report *IUE* observations of five blue, low-metallicity, star-forming galaxies sufficiently redshifted to permit detection of Lyα. Two of the galaxies exhibit Lyα emission at modest levels far below the recombination limit; two objects have Lyα in absorption. These observations confirm and extend earlier work which indicates that relatively unevolved galaxies do not exhibit striking Lyα emission signatures, even when strong ultraviolet continuum emission from hot stellar populations is observed.

In the complete sample of blue galaxies observed at Lyα (13 objects), there is evidence for the correlation of Lyα emission with metallicity expected if Lyα were destroyed by dust absorption. This correlation suggests that primeval galaxies could have significant Lyα emission if they have extremely low metallicity. Extrapolation of these results to primeval galaxies remains uncertain; the escape of Lyα depends upon the history of metal enrichment and upon both the spatial and velocity distribution of the gas. We suggest that trapping of Lyα in H II regions surrounded by large amounts of neutral material is responsible for the destruction of a substantial fraction of the Lyα flux in normal star-forming galaxies.

Dust absorption affects Lyα line emission more than the UV continuum. Near-infrared continuum searches for primeval galaxies might thus be more effective than searches at Lyα.

Subject headings: galaxies: stellar content — stars: formation — ultraviolet: spectra

I. INTRODUCTION

One of the important and intriguing problems in modern cosmology is the detection of galaxies at large redshift that are forming stars for the very first time—"primeval galaxies" (hereafter PGs). Knowlege of the spectral characteristics of such objects is required to design searches for primeval galaxies and to recognize them (Koo 1985). There are at least two approaches to the prediction of PGs spectra: (1) modeling the characteristics of low-metallicity star formation regions, and (2) observing nearby objects with spectra strongly dominated by recent star formation.

Simple theoretical models of PGs (without dust) predict strong Lyα emission, up to 6%–7% of the total luminosity (Partridge and Peebles 1967; Meier 1976). However, because the escape of Lyα depends sensitively on the column densities of neutral hydrogen and dust in PGs (cf. Osterbrock 1971), these results are uncertain. Observations of Lyα emission from low-metallicity, actively star-forming blue galaxies provide tests of models for the escape of Lyα in conditions approaching those which might occur in PGs.

Meier and Terlevich (1981) observed two blue galaxies with sufficiently large redshifts that the spectral region near Lyα could be observed with the *IUE* satellite. Their spectra indicated that the Lyα emission is substantially weaker than predicted in simple models. In an earlier paper (Hartmann, Huchra, and Geller 1984, hereafter Paper I) we discussed ultraviolet and optical spectra of three other blue star-forming galaxies with similar redshifts. The Lyα emission from these galaxies is weak or undetectable, despite the extremely strong Balmer line emission of all three objects. Deharveng, Joubert, and Kunth (1986) observed three objects: Lyα is undetected in one, weak in another, and strong in the third galaxy. In contrast, Djorgovski *et al.* (1985) and McCarthy *et al.* (1987) have found objects at high redshift that exhibit very strong Lyα emission ($W_\lambda = 10^3$ Å); thus at least some classes of objects can be detected in Lyα searches.

In an attempt to clarify the complex nature of the Lyα problem, we obtained ultraviolet spectra of five more blue galaxies. We detect weak Lyα emission from two of the systems. Two of the five objects show evidence for Lyα *absorption.* The sample of 13 blue galaxies observed with *IUE* shows an anticorrelation of Lyα emission with metallicity. These results again suggest that Lyα emission may not be strong in primeval galaxies unless the metallicity is significantly less than 0.1 solar.

We discuss the new observations in § II. Section III contains a discussion of destruction mechanisms for Lyα. We also examine the implications of the *IUE* results for detection of PGs, and we contrast the results with the Djorgovski *et al.* (1985) detection of objects at high redshift with strong Lyα emission.

II. OBSERVATIONS

a) IUE Observations

Table 1 lists the program objects for which ultraviolet spectra covering the range 1200–2000 Å were obtained using the SWP camera of the IUE spacecraft in low-dispersion mode. Details of the spacecraft and instrumentation are given in Boggess *et al.* (1978*a*, *b*). The spectra were taken through the large aperture (20″ × 10″; the short dimension is in the disper-

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[1] Research reported herein used the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

[2] Guest Observer, *International Ultraviolet Explorer.*

TABLE 1

GALAXY PROPERTIES

Name (1)	B (2)	$U-B$ (3)	cz (4)	$D_1 \times D_2$ (5)	*IUE* (SWP) (6)	Exposure (minutes) (7)
Mrk 66.....	15.4	−0.31	6345	19″ × 14″	24384	930
Mrk 309.....	15.4	−0.46	12620	27 × 13	24383	840
Mrk 347.....	14.9	−0.30	5820	19 × 19	27190	860
Mrk 499.....	15.0	−0.26	7685	15 × 15	26961	726
BSO 234.....	17.5	−0.43	17990	5 × 4	24594	860
	17.5	−0.43	19990	5 × 4	26343	795

sion direction). Figure 1 shows the spectra for all of the objects; Figure 2 (Plate 1) is a montage of photowrites.

Table 1 lists exposure times for the program objects. The flux calibration is from Bohlin and Holm (1980). These long exposures exhibit a number of radiation noise spikes or "hits," which we manually removed from the spatially resolved (line-by-line) data files. We then added the lines together to produce the total flux. Since galaxies can have spatially extended ultraviolet emission, and since there can be offsets between the ultraviolet and optical centers of light, there is uncertainty concerning which spatial lines within the large aperture to add up for each spectrum. Our limits were a subjective compromise between incorporating all the UV flux and avoiding the inclusion of too much noisy background. We used lines 25–31, 24–31, 26–31, and 25–30 to extract the spectra of Mrk 309, Mrk 66, and BSO 234 (SWP 24594 and SWP 26343), respectively. Each line in these spectra corresponds to about 2″ on the sky, so that our extractions cover about 12″–16″ perpendicular to the dispersion axis. The spectra of Mrk 499 and Mrk 347 were extracted with the more recent *IUE* software which extracts twice as many spatial lines as before. We extracted lines 47–59 and 48–61 for Mrk 499 and Mrk 347, respectively, corresponding to about 13″ to 14″ perpendicular to the dispersion.

Optical properties of the program galaxies are also listed in Table 1. The optical dimensions were measured on the Palomar Observatory Sky Survey (Huchra 1977) and correspond to a B isophote of roughly 23.5 mag per square arcsecond. These dimensions are generally small. Thus most of the ultraviolet emission should be contained within the 20″ × 10″ *IUE* large aperture.

Tables 2 and 3 contain a summary of ultraviolet continuum fluxes, Lyα fluxes, and absorption line equivalent widths. Below we discuss the properties of individual objects.

Mrk 66.—The optical image of this system is extended E–W, with a size of 14″ × 19″. Mrk 66 is clearly extended (~10″) in our *IUE* spectrum (Fig. 2) taken at a position angle of −124°. This object has a very strong blue continuum which rises toward short wavelengths. Although the *IUE* sensitivity drops precipitously below 1200 Å, we still detect continuum emission in the 1150–1200 Å region.

We observe spectral features (Fig. 1*a*) at wavelengths corresponding to Lyα, O I, and C IV redshifted by the galaxian velocity of 6345 km s^{-1}. The C IV feature is consistent with ultraviolet spectra of hot stars. The O I feature probably arises in the interstellar material of Mrk 66. The Lyα flux (Table 2) is the emission above the continuum level extrapolated from longer wavelengths. We may underestimate the flux by a factor of ~2 if the emission is situated on an underlying absorption feature (see discussion in Paper I).

In general, the spectrum is very similar to that of Mrk 357 (Paper I), except that the C IV absorption appears weaker in Mrk 66.

Mrk 309 = IV Zw 121.—Osterbrock and Cohen (1982) found that this object has emission in a band near 4650 Å characteristic of Wolf-Rayet stars. We see no evidence for characteristic UV spectral features of many Wolf-Rayet stars (Fig. 1*b*), e.g., strong He II λ1640 emission or P Cygni Si IV λ1400 and C IV λ1550 profiles (Nussbaumer *et al.* 1982). Osterbrock and Cohen suggest that only about 9% of the light at λ4650 comes from Wolf-Rayet stars, and estimated that the number of O stars is comparable to the number of Wolf-Rayet stars. The inclusion of O stars may dilute the Wolf-Rayet features sufficiently that they are unobservable, given the low signal-to-noise values of our spectrum. The strengths of ultraviolet lines characteristic of Wolf-Rayet stars also depend on the mean spectral type of the stars. Osterbrock and Cohen suggest an average type ~WN8–WC8, which have weaker emission lines than earlier WNs and WCs (Nussbaumer *et al.* 1982).

The apparent continuum rise near 1650 Å followed by a decrease in emission near 1700 Å is of questionable reality. A particle radiation event crosses the spectrum in the 1600–1650 Å region (see Fig. 2), and although we have removed the most obvious noise spike it is not possible to eliminate the effects on the spectrum in this region.

TABLE 2

ULTRAVIOLET FLUXES[a, b]

FEATURE (1)	MRK 66 (2)	MRK 309 (3)	MRK 347 (4)	MRK 499 (5)	BSO 234 SWP 24594 (6)	BSO 234 SWP 26343 (7)
Lyα.........	0.72	<0.1	<0.4	<0.26	0.37	0.20
Continuum (integrated over 100 Å bins):						
1300–1400.........	10.9	0.94	5.5	9.5	1.1	0.9
1400–1500.........	10.4	1.7	5.5	9.6	0.9	0.7
1500–1600.........	9.3	2.0	4.7	8.5	1.2	0.6
1600–1700.........	8.2	2.3	5.4	8.6	1.0	1.0
1700–1800.........	7.2	1.9	4.8	7.8	1.4	0.7
1800–1900.........	6.9	3.0	4.7	7.2	1.3	0.6

[a] Fluxes measured at Earth in units of 10^{-13} ergs cm^{-2} s^{-1} (Lyα feature; continuum integrated over 100 Å bins).

[b] Emission fluxes. In cases where Lyα absorption is observed, the flux upper limit comes from integrating over one resolution element centered near Lyα in the rest frame of the galaxy.

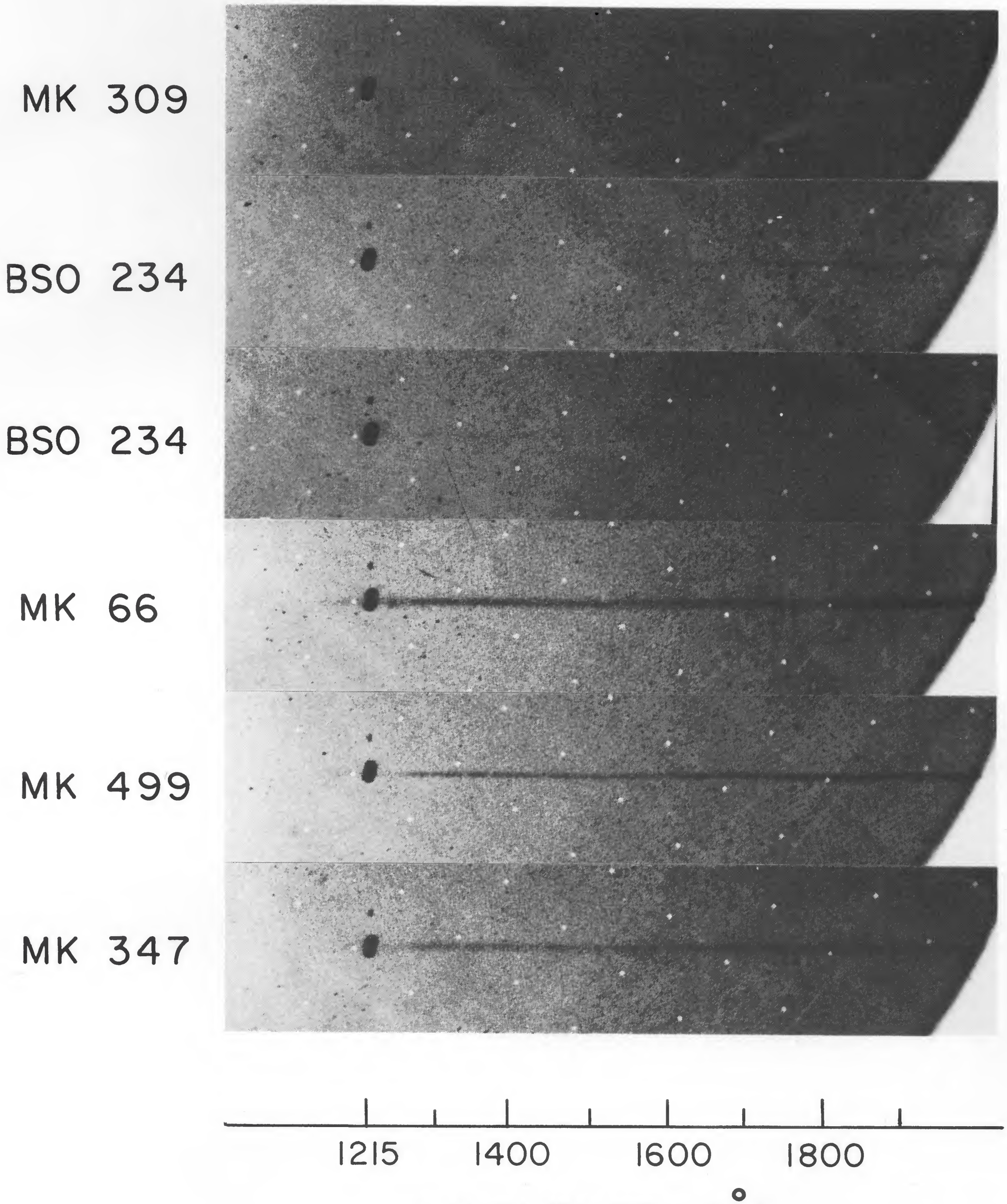

FIG. 2.—A montage of photowrites for (*top to bottom*) Mrk 309, BSO 234 (SWP 24594), BSO 234 (SWP 26343), Mrk 66, Mrk 499, and Mrk 347

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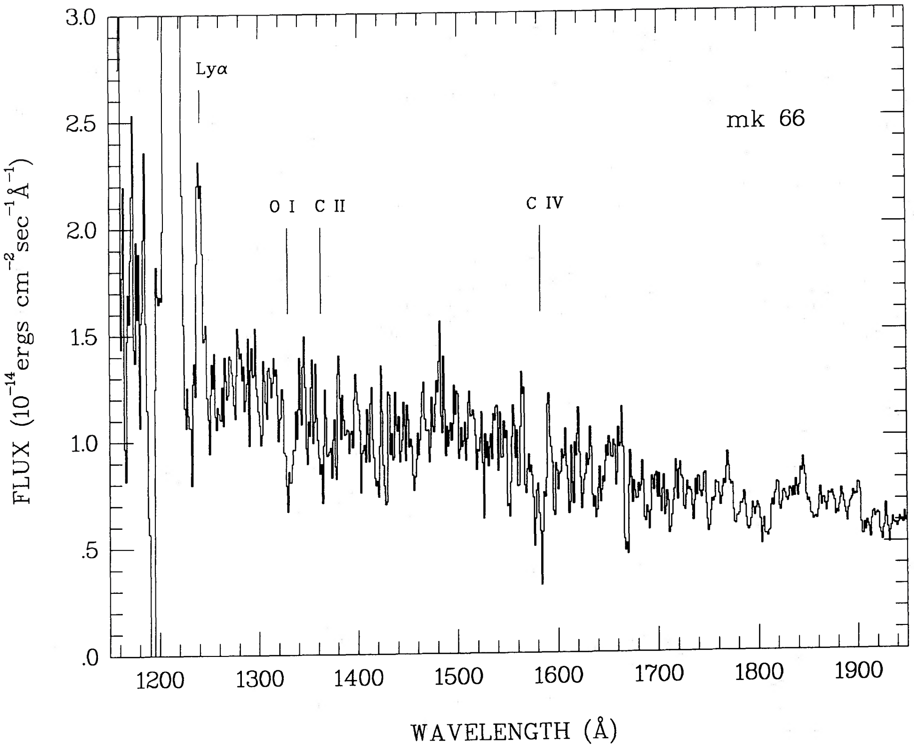

FIG. 1*a*

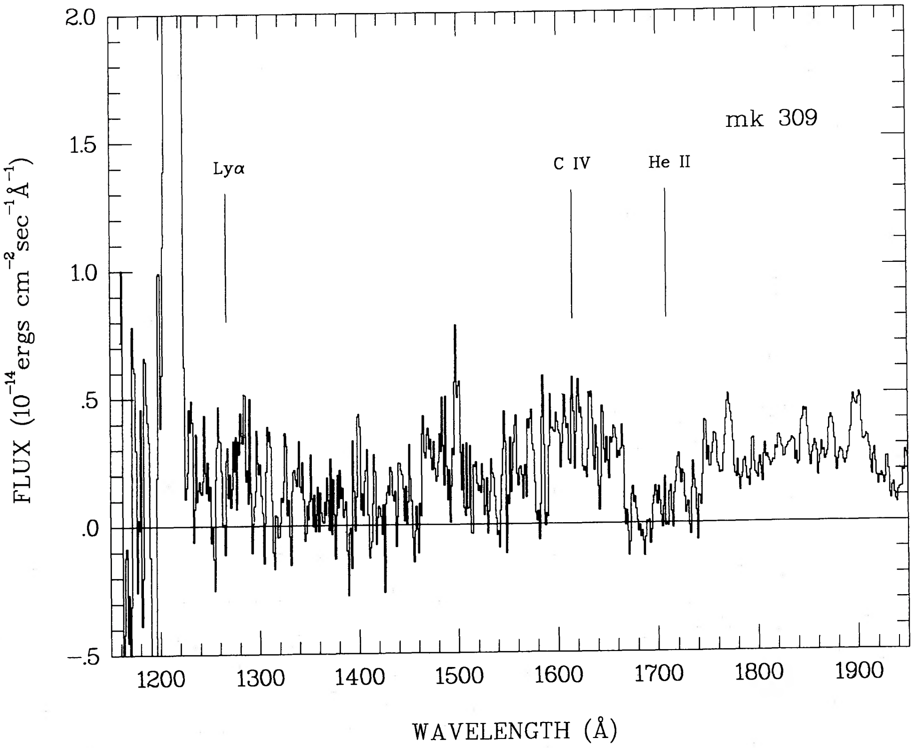

FIG. 1*b*

FIG. 1.—*IUE* SWP spectra of (*a*) Mrk 66 (*b*) Mrk 309, (*c*) Mrk 347, (*d*) Mrk 499, and (*e*) BSO 234: SWP 26343 (*top*) and SWP 24594 (*bottom*). The wavelengths of important lines in each galaxy are indicated.

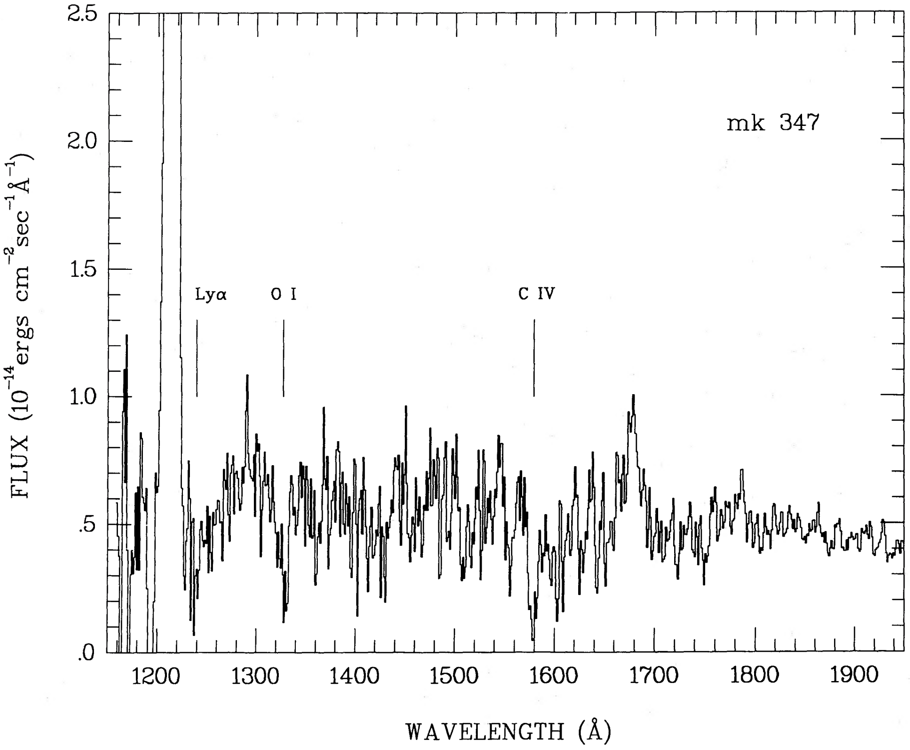
mk 347
Lyα
O I
C IV
FLUX (10^{-14}ergs cm^{-2}sec^{-1}Å^{-1})
WAVELENGTH (Å)
2.5
2.0
1.5
1.0
.5
.0
1200
1300
1400
1500
1600
1700
1800
1900

FIG. 1*c*

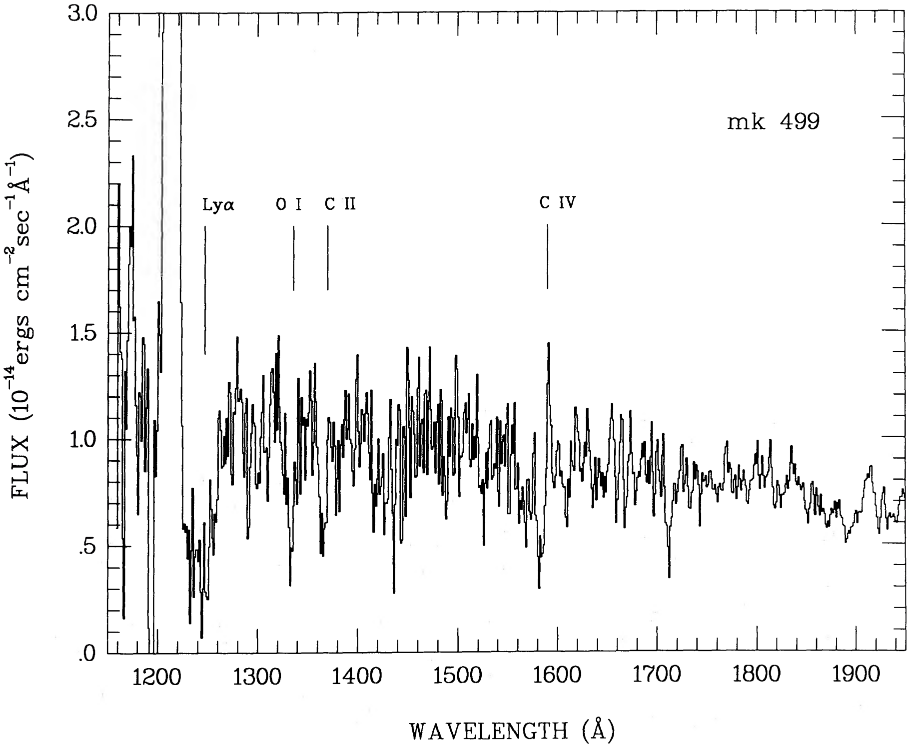
mk 499
Lyα
O I
C II
C IV
FLUX (10^{-14}ergs cm^{-2}sec^{-1}Å^{-1})
WAVELENGTH (Å)
3.0
2.5
2.0
1.5
1.0
.5
.0
1200
1300
1400
1500
1600
1700
1800
1900

FIG. 1*d*

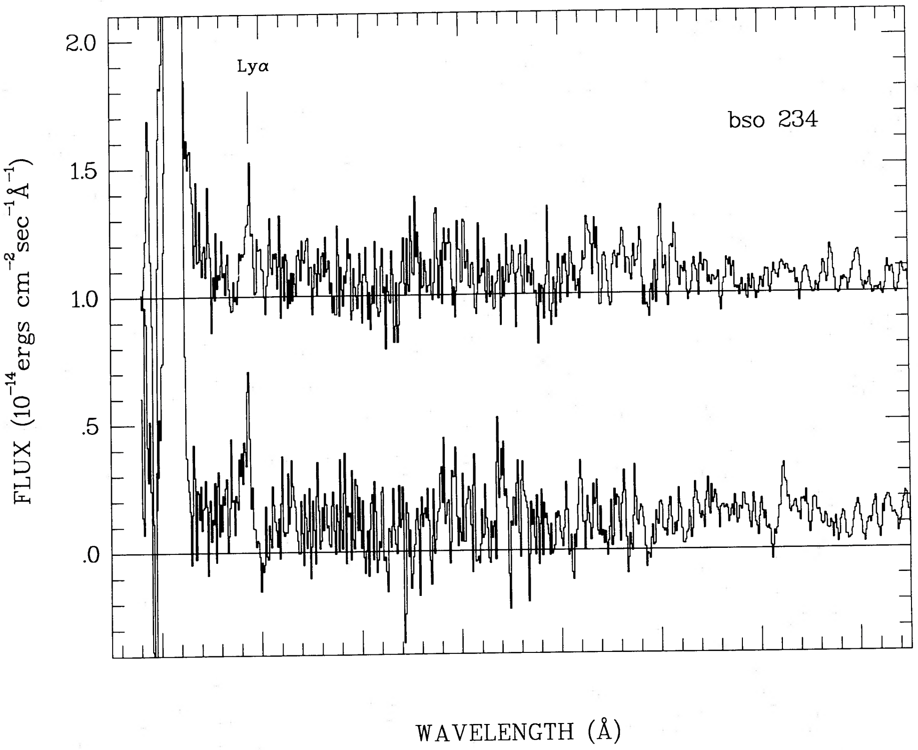

FIG. 1*e*

Mrk 347 = IC 1586 = III Zw 12.—Lyα emission is not detected; there is some indication of a continuum decline that could be the result of Lyα absorption centered at the galaxy redshift (Fig. 1*c*). The narrow absorption features correspond to O I and C IV at the redshift of Mrk 347.

Mrk 499 = I Zw 165.—We find a striking absorption feature in the continuum centered near λ1215 in the rest frame of the galaxy (Fig. 1*d* and Fig. 2). Although the flux calibration shortward of geocoronal Lyα is uncertain, the continuum emission between 1200 and 1150 Å suggest that the continuum downturn does not extend shortward of ~1175 Å. Our data are consistent with strong Lyα absorption at the rest velocity of Mrk 499. The expected stellar Lyα absorption equivalent widths are much smaller than indicated in this spectrum (see Paper I). The most likely explanation of this feature is that Mrk 499 is surrounded by a substantial cloud of neutral hydrogen. Broad absorption features are absent in most of the other program galaxies.

Our spectrum also shows O I λ1300 and C II λ1335 absorption at the velocity of Mrk 499; both components are probably interstellar. There is a hint of emission near the C IV λ1550 feature, which could naturally arise from the P Cygni features common in luminous hot stars.

BSO 234.—Although our spectra of this object, the highest redshift galaxy in our program, are extremely underexposed, weak emission is present near 1290 Å in both observations. Even after removal of the previously known spurious emission feature near 1280 Å (Hackney, Hackney, and Kondo 1982) and of an artifact in SWP 24594, both spectra suggest broad emission (more than 2 pixels wide) near 1290 Å. We conclude that we have probably detected redshifted Lyα in this galaxy, although the large variation in flux measurements between the two spectra indicates the uncertainty of our measurement.

b) *Optical Spectra and Analysis*

We use optical spectra to estimate metallicities of the objects in Table 4 which includes the galaxies observed by Meier and Terlevich (1981). Most of the data were obtained with the Multiple Mirror Telescope on Mount Hopkins. The Faint Object Grism spectrograph (Geary, Huchra, and Latham 1986) provided spectra over the wavelength interval ~4900–7000 Å. Observations of Mrk 66, Mrk 347, Mrk 499, 0842+163, and 1543+091 were made using a 1".3 × 18" slit, providing ~11 Å resolution.

[O III]/Hβ ratios measured from these spectra are given in Table 4. Because we used a CCD, these line ratios are accurate to better than 2%. We have estimated oxygen abundances from these ratios using the calibration of Pagel, Edmunds, and Smith (1980). This method is subject to considerable uncertainty. For 0842+163 and 1543+091, two program objects observed earlier by Meier and Terlevich (1981), the metallicities derived from the Pagel *et al.* calibration of [O III]/Hβ are about 0.1–0.2 dex larger than those derived by Meier and

TABLE 3

EQUIVALENT WIDTHS[a]

Feature (1)	Mrk 66 (2)	Mrk 309 (3)	Mrk 347 (4)	Mrk 499 (5)	BSO 234 (6)
Lyα	−6.0	<6[b]	~13.	~19.	~−25
O I	2.9	...	6.9	4.4	...
C II	1.7	...	...	3.7	...
C IV	3.1	...	8.4	4.6	...

[a] In Å; negative equivalent widths indicate *emission*, positive equivalent widths denote *absorption*.

[b] Absolute value of upper limit.

TABLE 4

Emission Equivalent Widths and Metallicities

Object	[O III]/Hβ	[O/H][a]	Lyα[b]	Lyα/Hβ
Mrk 309	0.55	+0.4[c]	<6	...
Mrk 496 (SW)	2.0	−0.1[c]	5	0.8
Mrk 347	1.7	−0.2[d]	<7	<0.5
Mrk 26	1.5	−0.3[c]	<6	<0.8
Mrk 499	3.0	−0.4[d]	<3	<0.5
0842+163	3.9	−0.5[c]	<10	<0.4
Mrk 66	4.8	−0.5[d]	6	1.1
BSO 234	8.2	−0.6[e]	30:	2:
Pox 124	...	−0.6[f]	...	<1.1
Mrk 357	4.2	−0.7[e]	10	1.1
Tol 41	...	−0.9[f]	48	1.9
1543+091	9.1	−1.0[e]	120	6.5
Pox 120	...	−1.1[f]	76	10.5

[a] Logarithmic oxygen abundance in solar units.

[b] Equivalent width of Lyα emission in Å. For Mrk 347 and Mrk 499, where Lyα absorption is observed, the equivalent width upper limit comes from integrating the flux in one resolution element centered near Lyα in the rest frame of the galaxy. Values for Mrk 357, Mrk 26, and Mrk 496 come from Paper I relative to the mean continuum level between 1300 Å and 1400 Å; results for 0842+163 and 1543+091 are taken from Meier and Terlevich 1981 relative to the 1300 Å continuum flux.

[c] Abundance measurement using a calibration ([O II] + [O III]) /Hβ ratio a calibrated by Pagel, Edmunds, and Smith 1980.

[d] Abundance measurement using calibration of [O III]/Hβ ratio as calibrated by Pagel, Edmunds, and Smith 1980. These measurements are uncertain; comparison with other methods suggests the resulting abundance may be systematically too high by 0.1–0.2 dex (see text).

[e] Abundance measurement from ratio of [O III] λ4363 to λ4959 + λ5007.

[f] Results for Pox 124, Tol 41, and Pox 120 from Deharveng, Joubert, and Kunth 1986.

Terlevich. They are similarly higher than the abundances we derived (Paper I) for Mrk 357 and 1543+091, where we can determine the oxygen abundance more accurately from a measurement of [O III] λ4363. Metallicities derived from the [O III]/Hβ ratio should be treated with caution.

BSO 234 was observed with the FOGS through an 5″ circular aperture for absolute spectrophotometry. The Hβ flux of BSO 234 measured in this way is approximately 1.5×10^{-14} ergs cm^{-2} s^{-1}. BSO 234 was also observed using the MMT spectrograph, which has wavelength coverage from ~3200–7000 Å with ~10 Å resolution, through a 1″ × 3″ aperture. We use $[I(\lambda 4959) + I(\lambda 5007)]/I(\lambda 4363)$ to derive an electron temperature of 1.1×10^4 K and we derive a logarithmic oxygen abundance (relative to solar abundances) of −0.6 dex, in good agreement with the abundances predicted by the Pagel *et al.* calibrations for ([O II] + [O III])/Hβ and [O III]/Hβ.

We observed Mrk 66 using the Reticon spectrograph on the Tillinghast 1.5 m reflector on Mount Hopkins. These spectra cover 4600–7100 Å at 6 Å resolution, and were made through a 3″.2 × 6″.4 slit. We have no direct calibration of the Hβ flux for Mrk 66, but if we combine the photometry through the 15″ aperture (Table 1) with an equivalent width of 15 Å from the 1.5 m spectrum, we arrive at an Hβ flux of 7×10^{-14} ergs cm^{-2} s^{-1}.

III. DISCUSSION

a) Parameter Dependence of Lyα Emission

Table 4 is a summary of the results from this paper, Paper I, Meier and Terlevich (1981), and Deharveng, Joubert, and Kunth (1986). Four of the 13 blue galaxies have Lyα/Hβ significantly greater than unity. Spectral synthesis models for reasonable stellar populations indicate that the amount of reddening must be very small in all of the objects except Mrk 309 ($E_{B-V} = 0.7$; Osterbrock and Cohen 1982). Nonetheless the Lya fluxes are far below the predictions of recombination theory. The observations are consistent with our earlier suggestion that small amounts of dust mixed with extended H I diminish the Lyα flux (see Paper I). Even very small amounts of dust are sufficient to reduce the Lyα flux substantially.

The equivalent width of Lya (relative to the 1300 Å continuum) is of greater interest for PG searches. Of the seven galaxies in the sample with detectable Lyα, BSO 234, 1543+091, Pox 120, and Tol 41 have significant Lyα equivalent widths. The value for BSO 234 is uncertain by as much as a factor of 2. In this sample PKS 1543+091 (Meier and Terlevich 1981) and Pox 120 (Deharveng, Joubert, and Kunth 1986) stand out.

The expanded sample of objects shows evidence for a correlation of Lyα with metallicity (Fig. 3). These results suggest that PGs may be detected in Lyα emission if they are of sufficiently low metallicity. However, there are only two objects, PKS 1543+091 and Pox 120, which have Lyα equivalent widths sufficiently large to be encouraging for current PG searches.

b) Mechanisms for Lyα Destruction

The most plausible mechanism for removal of Lyα photons is absorption by dust. Most of our blue galaxies show little evidence for reddening, and exhibit strong UV continuum emission. Dust absorption of Lyα is plausible only if multiple scattering in neutral hydrogen selectively increases the path length of Lyα photons through dusty regions (Auer 1968). Here we show that this mechanism can just barely account for the data.

The fraction of Lyα photons escaping from a static slab of uniformly distributed scatterers is

$$f_{\rm esc} \approx \exp\,[-0.8(L\tau_{\rm abs})^{0.7}] \qquad (1)$$

(Bonilha *et al.* 1979). Here $\tau_{\rm abs}$ is the dust absorption optical depth to the source (assumed to be isotropically emitting at the slab midplane) and L is the relative increase in path length caused by multiple scattering of Lyα in neutral hydrogen. The increase in path length is approximately

$$L \approx 1 + 2\ln\tau/(1 + 0.3a\tau)^{2/3} + (6.5a\tau)^{1/3}\,. \qquad (2)$$

Here τ is the Lyα line center optical depth to the photon source and a is the damping parameter.

We have direct evidence in two of the objects in Table 4 for the neutral hydrogen required to absorb Lyα. The large width of Lyα absorption in Mrk 499 must be produced by absorption on damping wings, because the observed FWHM of ~36 Å, ~8700 km s^{-1}, is unlikely to be produced by Doppler motions. Adopting an equivalent width of ~19 Å, we infer a column density of ~7×10^{20} cm^{-2}. Alternatively, the line profile suggests a column density $n_{\rm H}R \approx 4 \times 10^{21}$ cm^{-2}. The discrepancy between these two results is probably caused by complications in the scattering geometry. For the case of Mrk 357 we use the observations of 21 cm emission by Bothun *et al.* (1984) to make an estimate of the neutral hydrogen column density. If the neutral hydrogen responsible for this radio emission is uniformly distributed in a sphere of 10 kpc radius, the radial column density would be ~2.5×10^{21} cm^{-2}.

Neutral hydrogen column densities of 10^{21} cm^{-2} imply $\tau \approx 3 \times 10^6/(\delta v/10$ km s$^{-1})$. For line optical depths between

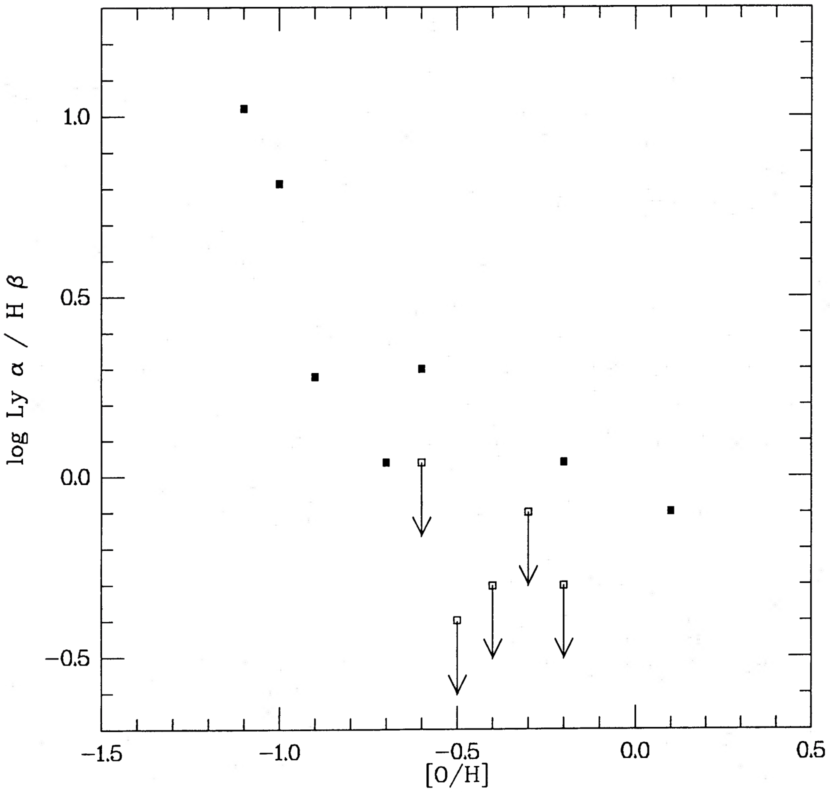

FIG. 3.—The Lyα/Hβ ratio as a function of [O/H]. Arrows denote upper limits

10^2 and 10^6, L varies between about 10 and 20 (eq. [2]). Thus we conclude that our program galaxies are likely to have enough neutral hydrogen to enhance dust absorption of Lyα by large amounts.

Setting $L \approx 20$ in equation (1), the escaping Lyα flux is reduced by a factor of 20 (to obtain Lyα/Hβ ≈ 1) if $\tau_{\rm abs} \approx 0.3$ at 1215 Å. The total extinction corresponding to this absorption optical depth depends upon the unknown albedo of dust at this wavelength. Choosing a plausible value of 0.7 for the ultraviolet albedo (Savage and Mathis 1979) the total extinction is $A(1215) \sim 1$ mag. If the extinction law has the same shape as the "average" galactic interstellar extinction curve (Savage and Mathis 1979), then $E(B-V) \approx 0.1$ mag. The required extinction for Lyα destruction is consistent with observational limits, as $E(B-V) = 0.1$ would be difficult to detect from either the Balmer emission line decrement or effects on the far-UV continuum. [We also note that for $E(B-V) = 0.1$, standard galactic extinction law, and dust to gas 0.1 times the solar neighborhood value to adjust for low metal abundances, the implied hydrogen column density is $\sim 5 \times 10^{21}$ cm^{-2}.] However, we emphasize that we have no direct evidence for dust in any of the program objects except for Mrk 309 (Osterbrock and Cohen 1982).

Equation (1) implies large variations in the Lyα/Hβ ratio for small variations in line and dust optical depths. In contrast, four of the 13 objects in Table 4 have ratios ~ 1. Selection effects may partially underlie this result; we would have difficulty measuring smaller Lyα emission fluxes (equivalent widths typically <6 Å). Alternatively, the escape of Lyα may be strongly affected by nonuniform covering of the sources by neutral hydrogen and dust; in other words, Lyα photons escape through "holes." The "covering fraction" may be more important in setting the amount of escaping flux than the exponential dependence of the observed fluxes on small variations in absorption properties (eq. [1]).

c) *High-Redshift Systems*

Djorgovski *et al.* (1985) observed strong Lyα emission from a "probable companion galaxy" to the QSO PKS 1614+051 at a redshift of 3.2. Schneider *et al.* (1986) found a similar object associated with 2016+112. Both objects exhibit strong Lyα, N v, and C IV emission. McCarthy *et al.* (1987) found a cloud of ionized gas associated with 3C 326.1 exhibiting only Lyα emission and an extremely weak continuum. Djorgovski *et al.* suggest that these objects may be newly formed galaxies, and that these observations provide new hope for primeval galaxy searches based on the detection of Lyα emission.

The spectra of the companions to PKS 1614+051 and 2016+112 differ strongly from the spectra of blue galaxies in aspects other than the Lyα strength. Although C IV P Cygni profiles may be detected in hot luminous stars, the very strong C IV emission seen in the high-redshift objects is not observed in blue galaxies, nor is it expected in gas ionized by normal populations of stars (e.g., Huchra *et al.* 1983). If C IV is collisionally ionized, the gas temperature must be of the order of 10^5 K, unlikely in an H II region. Photoionization to C^{+4} followed by recombination is more plausible. The photons responsible for such ionization must have energies of at least 64 eV, and such radiation is not emitted by stars with effective temperatures less than 100,000 K (cf. Hummer and Mihalas 1970). We can only conclude that the emission lines produced in the Djorgovski *et al.* object are produced by an ionizing radiation field much harder than that expected from a normal population of early-type stars, e.g., a QSO-type radiation field. It is possible that this object is excited by the neighboring QSO (Bergeron 1976; Hu and Cowie 1987).

The cloud of ionized gas associated with 3C 326.1 (McCarthy *et al.* 1987) does not exhibit detectable C IV emission. However, this object, like the companion of PKS 1614+051, has a Lyα velocity width of ~ 1000 km s^{-1}, characteristic of active objects. In active galaxies, the large velocity widths as well as lack of dust in the broad-line emision regions aid the escape of Lyα. (Lya photons at velocities beyond the range of neutral hydrogen velocities obviously will not be multiply scattered.) In normal galaxies, the widths of the emission lines should reflect typical velocities of stars and gas within the galaxy, $\lesssim 300$ km s^{-1}.

McCarthy *et al.* (1987) attempt to fit the 3C 326.1 gas cloud into the context of galaxy formation by suggesting that the large velocity dispersion is due to enhanced supernova ejection. It seems unlikely that the bulk of the H II regions in a forming galaxy will have such a large velocity dispersion.

While the high-redshift objects may well be young galaxies, the strong Lyα emission observed is probably not produced by early-type stars. In order to understand the underlying stellar population (if any), it would see necessary (unfortunately) to make better *continuum* observations.

d) Appearance of Primeval Galaxies

The implications of our results for the appearance of primeval galaxies depend sensitively on the evolution of their dust content. Standard models of galaxy evolution and star formation (Larson 1974; Kaufman 1975) suggest that PGs will only be observable, if at all, in later stages of evolution where they have condensed or collapsed substantially in volume (e.g., Meier 1976). Meier and Terlevich (1981) suggest that in this collapsed phase, metal enrichment is likely to be rapid, quickly resulting in solar abundances in the interstellar medium and large amounts of dust. This picture implies quantities of dust sufficient not only to get rid of Lyα emission but also to absorb much of the ultraviolet continuum. Koo (1985) suggests that UV absorption may become substantial for metal abundances $\geq 10^{-2}$ solar. These estimates of UV continuum absorption present an overly pessimistic view of the (rest-frame) ultraviolet luminosities of PGs, based on the available sample of blue galaxies, and on *IUE* observations of nearby blue objects with a range of metalicities (Lequeux *et al.* 1981; Huchra *et al.* 1982; Huchra *et al.* 1983; Viallefond and Thuan 1983; Hartmann, Huchra, and Geller 1984).

The correlation between Lyα escape and metallicity suggests that strong Lyα emission should be detectable from low-metallicity, nearly dust-free PGs. Whether such dust-free PGs existed (for very long) is another question. The low success rate for detection of objects in Lyα searches (Spinrad 1987; Hu and Cowie 1987) suggests that sufficiently dust-free star-forming objects are rare.

Kunth and Sargent (1985) have argued that H II regions in star-forming galaxies will have a minimum metal abundance $\sim 10^{-2}$ solar, even if the gas is initially metal-free. The input from massive stars contaminates the region on a time scale of $< 10^7$ yr. If Lyα absorption *within* H II regions is important, the dust-free time scale for PGs may be very short, limiting the number with strong Lyα emission.

Spitzer (1978) pointed out that a high density H I region surrounding the ionized gas may act like a scattering layer which reflects the photons back into the H II region. For large H I optical depths, Lyα photons can probably be scattered many times across the H II region. Because the column density of protons in a giant H II region can be of the same order of magnitude as the neutral hydrogen column densities discussed here, and because photons might be reflected many times across the H II region, absorption by dust mixed with the ionized gas might be more important than absorption in the extended H I cloud. With this mechanism, Lyα could be absorbed with considerably less dust extinction than indicated in the homogeneous models. Detailed calculations are necessary to sort out the relative importance of these effects.

Continuum searches for PGs might be more successful than Lyα searches because the continuum is less sensitive to extinction by small amounts of dust. The discussion of high-redshift objects in § III*c* shows that continuum studies are essential to detect the underlying young stellar population. Near-infrared imaging might be the best method to detect forming galaxies at redshifts between 5 and 10.

IV. CONCLUSIONS

Blue galaxies with metallicities ≥ 0.1 times solar have weak or absent Lyα emission. There is evidence for increasing Lyα emission with decreasing metallicity.

We attribute the reduction of Lyα fluxes from recombination values as due to absorption of multiply scattered Lyα by dust. The dust may be mixed in with the extended H I in which these galaxies are embedded. Scattering by dust internal to the H II regions may also be important. Calculations of Lyα trapping in H II regions surrounded by large amounts of neutral hydrogen would be useful to understand why the Lyα/Hβ ratio is so frequently of order unity. Observations with ASTRO or some other more sensitive instrument of Lyα emission from individual H II regions in nearby galaxies would help in discriminating among the models.

The prognosis for Lyα searches for PGs is mixed. The absence of strong Lyα emission from nearby star-forming galaxies only indicates that PGs must have metallicities $\lesssim 0.1$ solar for Lyα to be readily detectable. Even this statement requires cautious interpretation in light of the uncertainties in understanding the radiative transfer of Lyα in these systems. If the Lyα photons are trapped in the H II regions where they originate, primeval galaxies would be visible at Lyα for a timescale $\lesssim 10^7$ yr.

The objects at high redshift which were found in Lyα searches by Djorgovski *et al.* (1985), Schneider *et al.* (1986), and McCarthy *et al.* (1987) seem to differ significantly in their physical properties from the nearby star-forming galaxies we have observed with *IUE*. The larger velocity width of Lyα in the high-redshift objects along with dust destruction in an active nucleus are probably among the important distinguishing features. Continuum properties of these objects would provide a much better indication of the relationship between these objects and PGs.

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