Coordinated UV-optical observations of quasars: the evolution of the Lyman absorption

S. Cristiani 1, E. Giallongo 2, L. M. Buson 3, C. Gouiffes 4, F. La Franca 1

1 Dipartimento di Astronomia della Università di Padova, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy
2 Osservatorio Astronomico di Roma, Via dell’Osservatorio, I-00040 Monteporzio, Italy
3 Osservatorio Astronomico di Padova, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy
4 European Southern Observatory, K. Schwarzschild Strasse 2, D-8046 Garching, Germany

Received May 27, accepted Sep 24, 1992

Abstract. The average flux decrement shortward the Ly\(\alpha\) emission, due to the well-known “forest” of absorptions, has been measured in the spectra of 8 quasars. Quasi-simultaneous optical and IUE observations of the two low redshift quasars PKS 0637–75 \((z=0.654)\) and MC 1104+16 \((z=0.632)\) have been carried out, obtaining relatively high S/N, spectrophotometrically calibrated data on their energy distribution from the rest frame H\(\beta\) to the Lyman continuum. Six more quasars in the redshift range 2.5-3.4 have been observed in the optical domain. For all the quasars the “intrinsic” continuum slope and normalization have been estimated longward the Ly\(\alpha\) emission and extrapolated towards the Lyman continuum to measure the average depressions, which have been compared with the model statistics of the Ly\(\alpha\) clouds. When all the known classes of absorbers are taken into account with plausible values for their equivalent width distribution and evolution, a good agreement is obtained with the observations. The results for the observed continuum decrement at \(z \sim 0.65\) are identical to those predicted by the evolution with redshift of the number of Ly\(\alpha\) forest systems including the HST data and within 2\(\sigma\) of the predicted value using the “standard” Ly\(\alpha\) evolution (as determined only at high \(z\)).

Key words: Quasars: general – Intergalactic medium

1. Introduction

Considerable information about non-luminous extragalactic matter has been gained by studying the absorption features in quasar spectra. Particularly interesting in this respect is the issue of the evolution of the absorbers responsible for the “Ly\(\alpha\) forest systems”. It is generally accepted that they are originated by intergalactic primordial clouds (Sargent et al., 1980) and as such distinguished - although recent observations tend to blur this difference - from the less numerous “metal-line systems”.

Optical spectroscopy at high resolution available for a few QSOs at \(z \sim 3\) shows a high number of hydrogen absorption lines whose statistical properties can be represented, in terms of the number density of hydrogen clouds, by a power-law in redshift with index \(\sim 2\), indicating a cosmological evolution of the absorbers.

At low resolution this “forest” of absorptions appears as a steepening of the continuum slope in the region shortward the Ly\(\alpha\) emission as compared to the slope defined on the red side of Ly\(\alpha\) (e.g. Steidel & Sargent, 1987). The average flux decrements \(D_A\), between Ly\(\alpha\) and Ly\(\beta\) emissions, and \(D_B\), between Ly\(\beta\) and the Lyman limit have been introduced to study the average properties of the absorption (Oke and Korycansky 1982, Steidel and Sargent 1987). These quantities are, within relatively large limits, independent of the instrumental resolution, at least as far as the true continuum can be reliably extrapolated from the unabsorbed (red) region.

Using the material available in the literature (Bechtoldt et al., 1984; O’Brien et al., 1988; Oke and Korycansky, 1982; Schneider, Schmidt and Gunn, 1989; Steidel and Sargent, 1987) together with new optical data obtained by us at high redshifts, we have tried to disentangle the evolutionary details of the Ly\(\alpha\) absorbers (Giallongo & Cristiani, 1990). Excess absorption with respect to the \(\gamma \sim 2\) evolution is found both at high and low redshifts (as could be expected since the evolutionary law has been normalized at \(z\sim 3\) where the bulk of the optical data has been obtained). The presence of different populations of absorbers might be suggested as well as a change in the physical conditions of the clouds. In any case the slower evolution found at low redshifts resembles that of metallic lines, perhaps indicating a link with the evolution of normal galaxies.

The acquisition of new material is important especially at low redshifts, because in this region the uncertainties are still rather large and the constraints to the functional form of the evolution of the absorbers imposed by the data at the lower extreme of the observable redshift range can be particularly strong. For this reason we have observed 2 bright QSOs (V...
\[ \sim 16 \] with \( z \simeq 0.65 \) (an especially convenient redshift for IUE observations since the QSO Ly\( \alpha \) emission falls then in the region of overlap between the SWP and the LWP cameras) to provide additional good quality spectra needed to clarify the situation. In addition, optical observations of 6 quasars have been carried out in the optical domain, in order to improve the statistics and the quality of the data at \( z \simeq 2.5 - 3.\)

2. UV Observations

Two consecutive IUE low-resolution long-wavelength spectra and one short-wavelength spectrum of PKS 0637–75 have been obtained on Dec. 25–26 1990 at VILSPA. One SWP and one LWP spectrum secured during a subsequent run on April 6–7 1991 allowed us a full coverage of the IUE spectral range (\( \lambda \lambda 1200-3300 \) \( \AA \)) also for MC 1104+167. Since the visual magnitude of both objects (V\( \sim \)16) is beyond the imaging capabilities of the IUE FES, a standard blind offset technique from nearby stars was adopted to put the target into the slit.

| Object       | Spectrum | Obs. Date | Exp. T. (m.) | ECC |
|--------------|----------|-----------|--------------|-----|
| PKS 0637–75  | SWP 10832| 80 Dec 12 | 416          | —   |
| PKS 0637–75  | LWP 13013| 88 Apr 10 | 120          | 335 |
| PKS 0637–75  | LWP 13016| 88 Apr 11 | 105          | 335 |
| PKS 0637–75  | LWP 13022| 88 Apr 12 | 120          | 338 |
| PKS 0637–75  | LWP 19471| 90 Dec 25 | 180          | 331 |
| PKS 0637–75  | LWP 19472| 90 Dec 25 | 215          | 341 |
| PKS 0637–75  | SWP 40461| 90 Dec 26 | 404          | 331 |
| MC 1104+167  | SWP 41309| 91 Apr 06 | 400          | 352 |
| MC 1104+167  | LWP 20094| 91 Apr 07 | 360          | 452 |
The exposure times spanned from 3 to 7 hours giving a S/N ratio $10 \div 15$ in the best exposed regions. Taking into account that PKS 0637–75 did not show significant UV variability over a decade, four pre–existing lower–quality spectra collected at GSFC between 1980 and 1988 have been included in our analysis. Their flux levels have been renormalized to the level observed in Dec 1990 and a weighted mean of all the data has then been carried out. A previous SWP spectrum of MC 1104+167 does not contain signal and was discarded. A complete log of used observations is reported in Table 1. This table also includes, when available, the VILSPA Exposure Classification Code (ECC) which gives an approximate measure of the image quality.

Both our spectra and previous data have been consistently re–extracted from the so–called line–by–line spectrum provided by the standard IUESIPS processing. These spectra are already wavelength calibrated and photometrically linearized. Our subsequent extraction includes removal of cosmic ray hits and camera reseau marks as well as subtraction of a smoothed nearby background giving a time–integrated net spectrum. The final absolute flux calibrated spectrum is obtained by multiplying by the proper calibration function and dividing by the exposure time. Since our data have been processed with the current version of IUESIPS, the present LWP ITF2 calibration function (Cassatella et al. 1988) has been adopted for long–wavelength spectra. The short–wavelength data have been calibrated by means of the standard SWP function (Holm et al. 1982). A test extraction including the signal weighting on the basis of the observed PSF did not improve significantly our final S/N ratio.

Both SWP and LWP data have been finally corrected for the time–dependent camera sensitivity degradation as proposed by Bohlin and Grillmair (1988) and Teays and Garhart (1990) respectively. The estimated absolute flux error does not exceed 0.05 dex in both cameras. The IUE spectra of both quasars are shown in Fig. 1.

### 3. Optical Observations

The journal of the optical spectroscopic observations carried out at the La Silla Observatory is given in Table 2.

---

**Fig. 2a.** Optical spectra of Q0053–4029, Q0126–4050, Q0249+0222, Q0254–0137, relative fluxes are in units of $10^{-16}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$
Table 2. Journal of the optical spectroscopic observations

| Name       | R.A. 1950.0 | Dec. 1950.0 | Date       | Telescope | Spectrograph | Slit width (arcsec) | Resolution (Å) | Sp. Range (Å) |
|------------|-------------|-------------|------------|-----------|--------------|---------------------|----------------|---------------|
| Q0053–4029 | 00 53 51.5  | –40 29 30   | 02 Sep 1987 | 3.6m      | EFOSC1       | 2.0                 | 15             | 3750-7000     |
| Q0126–4050 | 01 26 13.6  | –40 50 05   | 03 Sep 1989 | 2.2m      | B.&C.        | 2.0                 | 20             | 3400-8650     |
| Q0249+0222 | 02 49 42.4  | +02 22 57   | 30 Nov 1989 | 3.6m      | EFOSC1       | 2.0                 | 15             | 3700-7000     |
| Q0254–0137 | 02 54 07.9  | –01 37 49   | 30 Nov 1989 | 3.6m      | EFOSC1       | 2.0                 | 15             | 3700-7000     |
| Q0256–0000 | 02 56 31.8  | –00 00 29   | 02 Jan 1984 | 3.6m      | B.&C.        | 3.0                 | 20             | 4350-8320     |
| Q0301–0035 | 03 01 07.7  | –00 35 01   | 17 Oct 1984 | 3.6m      | B.&C.        | 2.0                 | 20             | 3700-8750     |
| PKS0637–75 | 06 37 23.3  | –75 13 38   | 20 Dec 1990 | 3.6m      | EFOSC1       | 1.5                 | 15             | 3700-7000     |
| PKS0637–75 | 06 37 23.3  | –75 13 38   | 19 Dec 1986 | 2.2m      | B.&C.        | 6.0                 | 30             | 3500-10000    |
| MC 1104+16 | 11 04 36.7  | +16 44 17   | 13 Apr 1991 | 1.5m      | B.&C.        | 2.0                 | 22             | 4800-8800     |

Fig. 2b. Optical spectra of Q0256–0000, Q0301–0035, PKS 0637–75, MC 1104+16

For the reduction process the standard MIDAS facilities available at the Padova Department of Astronomy and at ESO Garching have been used. The raw data were sky-subtracted and corrected for pixel-to-pixel sensitivity variations by division by a suitably normalized exposure of the spectrum of an incandescent source. Wavelength calibration was carried out
Fig. 3. \( \log(\nu) - \log(F_\nu) \) combined spectra of PKS 0637–75 and MC1104+16.

by comparison with exposures of Helium and Argon lamps. Absolute flux calibration was finally achieved by observations of standard stars listed by Oke (1974) and Stone (1977).

For both PKS 0637–75 and MC 1104+16 the optical spectrophotometry has been obtained quasi-simultaneously with respect to the IUE observations in order to minimize the effects of variability. Three spectra of PKS 0637–75 obtained on December 1986 were normalized to the flux level of Dec 1990 and merged with the 1990 spectrum.

The optical spectra of all the quasars are shown in Fig. 2a-b.

4. Measuring the average flux decrement

All the spectra have been corrected for galactic extinction according to Burstein & Heiles (1982) and rebinned to the QSO rest frame on the basis of their emission redshift, as shown in Fig. 3, in a \( \log(\nu) - \log(F_\nu) \) form.

The slope of the continuum has been estimated in the form of a power-law \( f_\nu \propto \nu^{-\alpha} \) (the dashed line in Fig. 3) on the basis of the “true continuum” regions at lower frequencies with respect to the Ly\( \alpha \) emission, and extrapolated to the regions \( A \) and \( B \), as defined by Oke and Korycansky (1982). The average flux decrements \( D_A \) and \( D_B \) have been computed according to the equation:

\[
D_i = < 1 - \frac{f_{obs}}{f_{int}} >, \quad i = A, B \tag{1}
\]

where \( f_{obs} \) and \( f_{int} \) are the observed and “intrinsic” fluxes per unit wavelength in the QSO rest frame.

As emphasized in Giallongo and Cristiani (1990), the evaluation of the flux decrements \( D_A \) and \( D_B \) is subject to many sources of uncertainty, closely related to the difficult estimate of the “intrinsic continuum”. At low redshifts these problems have relevant consequences on the interpretation of the data since, as shown below, the derived uncertainties (contrary to
the situation at high redshift) are of the same magnitude as the measured effect.

Composite quasar spectra (Cristiani and Vio 1990, Francis et al. 1991), used by us as a guide in the procedure of extrapolation, illustrate how few regions can be considered as indicators of the “true” continuum. In particular the excess emission around C III] (the blended Fe II 2000 Å complex) is likely to introduce a bias in the measurements for high redshift QSOs, in the sense of a steeper estimated continuum and a consequent underestimate of the Lyman absorption. Our low-redshift measurements, based on IUE+optical data, could therefore be more accurate but not homogeneous with respect to the high-redshift data, since the estimate of the “intrinsic continuum” is carried out on different rest-frame intervals. On the other hand, such a concern is probably less important than it may appear because a) in the present case, the only effect of the use of the optical+IUE data with respect to the IUE data only is to restrict the range of the possible continuum slopes to the steeper ones; b) the quasars used in the \( D_A \), \( D_B \) measurements have redshifts typically larger than those of the quasars used to construct the composite spectra, and for higher redshift QSOs the contribution of the Fe 2000 Å complex is probably less important (e.g. Giallongo, Cristiani, Trevese 1992).

To get an idea of the effects due to differences in the spectral ranges and/or resolutions it is interesting to note that the continuum slope estimated by us for PKS 0637–75 \( (\alpha = 0.30 \pm 0.05) \) is significantly flatter than the value obtained by O’Brien et al. (1988), 0.53±0.02, on the basis of IUE spectra and optical photometry, and that for MCI104+16 the spectral index obtained by Oke et al. (1984), 0.24 ± 0.1, on the basis of very low resolution optical spectrophotometry, is significantly flatter than ours, 0.48 ± 0.05. The above mentioned indices can also be compared with the “color-determined” values of Yu (1987) of 0.84 and 0.60 respectively.

Other non-negligible sources of uncertainty are the matching between the optical and IUE flux calibrations and, especially in the case of PKS 0637–75, the amount of galactic extinction adopted.

Since systematic errors are extremely difficult to evaluate, in Table 3 we have indicated as uncertainties in the \( \alpha \), \( D_A \), \( D_B \) values only the “internal” uncertainties deriving from the different possible choices of the continuum slope and normalization.

| Name            | \( z_{em} \) | \( E_{B-V} \) (mag) | \( \alpha_\nu \) (\( \lambda > 1250 \) Å) | \( D_A \) (1050-1170 Å) | \( D_A \) (1040-1190 Å) | \( D_B \) (920-1015 Å) | \( D_B \) (912-1020 Å) | i.s. Mg II EW (Å) |
|-----------------|-------------|-------------------|---------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| PKS 0637–75     | 0.654 ± 0.003 | 0.12              | 0.30 ± 0.05                     | 0.07 ± 0.04       | 0.06 ± 0.04       | 0.18 ± 0.05       | 0.21 ± 0.05       | 6.5 ± 0.5         |
| MC 1104+16      | 0.632 ± 0.002 | 0.02              | 0.48 ± 0.05                     | 0.04 ± 0.02       | 0.02 ± 0.02       | 0.11 ± 0.03       | 0.10 ± 0.02       | 4.0 ± 0.3         |
| Q0053–4029      | 2.758 ± 0.005 | 0.01              | 0.70 ± 0.08                     | 0.18 ± 0.04       | 0.18 ± 0.04       | 0.18 ± 0.04       | 0.18 ± 0.04       | 0.18 ± 0.04       |
| Q0126–4050      | 2.594 ± 0.005 | 0.01              | 0.35 ± 0.10                     | 0.23 ± 0.03       | 0.19 ± 0.03       | 0.19 ± 0.03       | 0.19 ± 0.03       | 0.19 ± 0.03       |
| Q0249+0222      | 2.805 ± 0.005 | 0.06              | 0.82 ± 0.08                     | 0.17 ± 0.03       | 0.14 ± 0.03       | 0.14 ± 0.03       | 0.14 ± 0.03       | 0.14 ± 0.03       |
| Q0254–0137      | 2.684 ± 0.005 | 0.04              | 0.53 ± 0.05                     | 0.20 ± 0.02       | 0.18 ± 0.02       | 0.18 ± 0.02       | 0.18 ± 0.02       | 0.18 ± 0.02       |
| Q0256–0000      | 3.367 ± 0.004 | 0.06              | 0.61 ± 0.05                     | 0.26 ± 0.02       | 0.22 ± 0.02       | 0.22 ± 0.02       | 0.22 ± 0.02       | 0.22 ± 0.02       |
| Q0301–0035      | 3.205 ± 0.005 | 0.06              | 0.54 ± 0.05                     | 0.30 ± 0.03       | 0.27 ± 0.03       | 0.27 ± 0.03       | 0.27 ± 0.03       | 0.27 ± 0.03       |

5. Comparison with models and conclusions

We have compared the measured average depressions \( D_A \) with the predictions derived on the basis of the model statistics of the Ly\( \alpha \) absorptions superimposed to a synthetic QSO spectrum as in Giallongo, Gratton & Trevese (1990) and Giallongo & Cristiani (1990).

As in the previous papers we have considered the following classes of absorbers.

(i) The Ly\( \alpha \) lines not associated with metal line systems. These systems evolve in redshift with an average distribution of restframe equivalent widths according to the following equation:

\[
\frac{\partial^2 N(z,W)}{\partial z \partial W} = \frac{A}{W^* (1+z)^\gamma} \exp (-W/W^*) \tag{2}
\]

A recent estimate of the Ly\( \alpha \) line distribution in the range \( 1.8 < z < 3.8 \) and \( 0.2 < W < 0.5 \) Å has been obtained from a small high resolution sample by Giallongo (1991). On average \( W^* = 0.2 \) Å and \( \gamma = 2.1 \) was found. For \( W > 0.5 \) Å a flatter distribution with \( W^* = 0.3 \) Å has been assumed following the equivalent width distributions obtained from large intermediate resolution samples. A set of random absorption redshifts is extracted according to equation (2) with \( \gamma = 2.1 \). We then associate to each redshift a random equivalent width extracted from a probability distribution \( P(W) \propto \exp (-W/W^*) \) using the above \( W^* \) values in the appropriate \( W \) ranges.

(ii) Ly\( \alpha \) lines associated with metal line systems. We adopt the same \( z,W \) distributions with \( \gamma = 0.68 \) (Sargent, Steidel & Boksenberg 1989) and \( W^* = 1.05 \) Å (Sargent et al. 1980) as in the previous papers.

(iii) Lyman \( \beta, \gamma, \delta \) are computed for each Ly\( \alpha \) using a standard curve of growth derived from a Voigt profile. We have adopted a Doppler parameter value of \( b = 20 \) Km s\(^{-1}\) for weak lines \((W < 0.5 \) Å\) and \( b = 40 \) Km s\(^{-1}\) for strong lines \((W > 0.5 \) Å\).

(iv) We have also included in the line statistics a population of damped systems with \( W^* \approx 10 \) Å to account for the average absorption observed at very high redshift \((z > 4)\), (see Giallongo & Cristiani 1990 for details). For each emission redshift we compute 100 synthetic QSO absorption spectra using Voigt profiles with natural damping only.
The available data and simulations at various $z_{\text{em}}$ for the average depressions $D_A$ are shown in Fig. 4. For $z_{\text{em}} > 2.5$ individual $D_A$ values are computed from optical spectra of QSOs taken by various authors at different resolutions (6–100 Å). For $z_{\text{em}} < 2$ average depressions are derived from IUE spectra.

We have represented both the data of O’Brien, Gondhalekar & Wilson (1988) and Bechtold et al. (1984). We note that the values derived by Bechtold et al. are systematically higher, probably because of the low resolution adopted in the optical spectra (80 Å) which could cause an overestimate of the continuum level at wavelengths longer than the Ly$\alpha$ emission.

When comparing observed and predicted $D_{A,B}$ values on the basis of the Ly$\alpha$ statistics, we have to remove the contribution of the interstellar absorption lines, that is non-negligible when the average depressions are very low (e.g. $< 0.1$). For example, in the high resolution spectrum of 3C 273 (Bahcall et al. 1991), we can evaluate a value of $D_A \approx W_{\text{tot}}/\Delta \lambda = 0.02$ due to the interstellar absorption lines. We can estimate the analogous contribution for PKS 0637–75 and MC 1104+16 by considering the interstellar absorptions observed in the 3C 273 spectrum in the range corresponding to the A region of PKS 0637–75 and MC 1104+16, and scaling their equivalent widths according to the ratio between the EW of the 2798 Å Mg II absorption feature observed in our quasars and the one in 3C 273. In this way an extra $D_A$ value of 0.009 is derived for PKS 0637–75 and of 0.006 for MC 1104+16.

After this correction we have, at $z \approx 0.65$, an average observed value for the two QSOs, $D_A = 0.047 \pm 0.013$ which is larger than but still consistent, within the relatively large uncertainties, with the one predicted by the redshift evolution of the Ly$\alpha$ lines $D_A = 0.026 \pm 0.015$. In this way, marginal evidence is found for a departure from the standard Lyman $\alpha$ evolution down to $z \approx 0.65$. The excess of absorption could be due to the presence of the diffuse component of neutral hydrogen (the Gunn-Peterson effect) or to a slower evolution towards low redshifts of the Ly$\alpha$ lines.

Indeed recent HST high resolution spectra obtained at lower redshifts $z < 0.3$ seem to imply a slower evolution with $\gamma \approx 0.7$ (Bahcall et al. 1992). Adopting this evolutionary rate from $z \approx 2.5$ down to $z = 0.65$ we obtain $D_A = 0.047 \pm 0.015$ in agreement with our observed absorptions. Thus no significant Gunn-Peterson effect is detectable in the interval $0.65 < z < 4.2$. 

**Fig. 4.** Comparison between the observations and the simulations for the average $D_A$ depressions. Crosses represent the average values from the Monte Carlo simulations. The contribution of the interstellar absorption lines has been subtracted to the $D_A$ values observed for PKS 0637–75 and MC 1104+16.
The implications of the change in the line statistics would be important for the physical models of the Lyα clouds and for the cosmological evolution of the intergalactic medium and the UV ionizing flux. In the standard scenario of pressure confined cloud model, the change in the cosmological evolution of the clouds is related to a quick drop of the UV ionizing flux at very low redshifts (Ikeuchi & Turner 1991).

The uncertainties involved in the process of estimating the continuum slope and normalization, matching the spectra obtained in different spectral ranges with different instruments and detectors, evaluating correctly the galactic extinction are such to indicate that an improvement of the present estimates at low redshifts with low-resolution spectrophotometry will be extremely difficult. Higher resolution line statistics at low z is obviously the way to follow.

Acknowledgements. It is a pleasure to thank Paola Andreani for helpful discussions and suggestions. Fabio LaFranca acknowledges the financial support of a research fellowship of the Fondazione Ing. Aldo Gini.

References

Adam, G., 1978, A&AS 31, 151
Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., Hartig, G. F., Bohlin, R., Junkkarinen, 1991, ApJ 377, L5
Bechtold, J., Green, F., Weymann, R. J., Schmidt, M., Estabrook, F. B., Sherman, R. D., Wahlquist, H. D. & Heckman, T. M., 1984, ApJ 281, 76
Bohlin, R. C., & Grillmair, C. J., 1988, ApJS 66, 209
Boyle, B. J., Shanks, T. & Peterson, B. A., 1988, MNRAS, 235, 935
Burstein, D. & Heiles, C., 1982, AJ 87, 1165
Cassatella, A., Ponz, D., Selvelli, P.L. & Vogel, M., 1988, ESA IUE Newsletter 31, 1

Cristiani, S. & Vio, R., 1990, A&A 227, 385
Ellingson, E., Yee, H. K. C. & Green, R. F., 1991, ApJ, 371, 49
Francis, P. J., Hewett, P. C., Foltz, C. B., Chaffee, F. H., Weymann, R. J. & Morris, S. L., 1991, ApJ 373, 465
Giallongo, E., 1991, MNRAS 251, 541
Giallongo, E., & Cristiani, S., 1990, MNRAS 247, 696
Giallongo, E., Gratton, R. G. & Trevese, D., 1990, MNRAS, 244, 450
Giallongo, E., Cristiani, S., & Trevese, D., 1992, ApJL, in press
Holm, A.V., Bohlin, R.C., Cassatella, A., Ponz, D., & Schiffer III, F.H., 1982, A&A 112, 341
Ikeuchi, S., & Turner, E. L., 1991, ApJ Lett., 381, L1
O’Brien, P. T., Gondhalekar, P. M. & Wilson, R., 1988, MNRAS 233, 801
Oke, J. B., 1974, ApJS, 27, 21
Oke, J. B., & Korycansky, D. G., 1982, ApJ 255, 11
Oke, J. B., Shields, G. A. & Korycansky, D. G., 1984, ApJ 277, 64
Sargent, W. L. W., Young, P. J., Boksenberg, A. & Tytler, D., 1980, ApJS 42, 41
Sargent, W. L. W., Steidel, C.C., & Boksenberg, A., 1989, ApJS 69, 703
Schneider, D. P., Schmidt, M., & Gunn, J. E., 1989, AJ 98, 1507
Schneider, D. P., Schmidt, M., & Gunn, J. E., 1991, AJ 101, 2004
Steidel, C. C., & Sargent, W. L. W., 1987, ApJ, 313, 171
Stone, R. P. S., 1977, ApJ 218, 767
Teays, T. & Garhart, M. P., 1990, NASA IUE Newsletter, 41, 94
Yu, K. N., 1987, Ap&SS 134, 35

This article was processed by the author using Springer-Verlag \LaTeX A&A macro package 1991.