## INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand comer and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality $6^{\prime \prime} \times 9^{\prime \prime}$ black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600


# THE PROXIMITY EFFECT IN THE SPECTRA OF QUASI-STELLAR OBJECTS AND THE EVOLUTION OF THE ULTRAVIOLET BACKGROUND FROM $\mathrm{Z}=4$ TO $\mathrm{Z}=0$ 

by<br>Jennifer Erin Scott

A Dissertation Submitted to the Faculty of the Department of Astronomy<br>In Partial Fulfillment of the Requirements<br>For the Degree of<br>Doctor of Philosophy<br>In the Graduate College<br>The University of Arizona

## UMí

UMI Microform 3053910
Copyright 2002 by ProQuest Information and Learning Company. All rights reserved. This microform edition is protected against unauthorized copying under Title 17, United States Code.

ProQuest Information and Learning Company 300 North Zeeb Road
P.O. Box 1346

Ann Arbor, MI 48106-1346

## THE UNIVERSITY OF ARIZONA © GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Jennifer Erin Scott
entitled The Proximity Effect in the Spectra of Quasi-Stellar
Objects and the Evolution of the Ultraviolet Background from $\mathrm{Z}=4$ to $\mathrm{Z}=0$
and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy


Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that $I$ have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.


## Statement by Author

This dissertation has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this dissertation are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

Signed:


## Dedication

I dedicate this work to my parents, Nolie Edward and Susan Elizabeth Scott, and to my sister, Maggie Suzannah.

## Acknowledgements

First and foremost, I would like to acknowledge and thank my parents, life mentors, and role models, Edward and Susan Scott. Without their love and support and that of my sister Maggie, the task of earning this Ph.D. would have been far more arduous.

I owe my scientific training primarily to my two advisors, Dr. Jill Bechtold and Dr. Matthias Steinmetz, who have taught me nearly everything I know about observational astronomy and theoretical astrophysics, respectively. Their guidance has been indispensible, and I thank them for all the opportunities they have given me. I also thank others at Steward Observatory and elsewhere who provided collaboration, encouragement, or just some food for thought along the way: Drs. Adam Dobrzycki, Varsha Kulkarni, Chris Impey, Buell Jannuzi, Phil Pinto, Romeel Davé, Craig Foltz, Peter Strittmatter, and Raymond White. I thank Dr. Eileen Friel for encouraging me to get a Ph.D., and I thank Miwa Morita for her work on the HST/FOS archive data.

I am grateful to all my fellow grads for providing such excellent examples of how to be a good scientist, but extra thanks must go to the officemates I have had during my years at Steward, especially to Audra Baleisis, Aimee Hungerford, and David Sudarsky. Other current or former UA astronomy or physics grads I thank in particular for great discussions about life, the universe, and everything are Mike Collins, Paul Harding, Eric Hooper, Chris Fryer, Dan M ${ }^{c}$ Intosh, Cathy Petry, Greg Rudnick, and Todd Thompson.

I extend thanks everyone in the Department, Business, and Director's Offices of Steward, especially Michelle Cournoyer, Catalina Diaz-Silva, Joy Facio, Sharon Jones, Kristen Morse, and Susan Warner, for making the many navigations through red tape virtually painless. I thank Carmen Henley for all the comic relief, and I thank Alan Koski, Jeff Fookson, and Patty Esterline for sharing their computer expertise.

I am very grateful to John Birkinbine for his love and support and to his parents, John and Seny, for the wonderful dinners, and for making me so welcome in their home. I am thankful for other Tucson friends: Kyle Bronsdon, Colby Campbell and Margaret Ford, Caren Crutcher, Brian Dilkes, Oscar Fowler, Deborah Koolbeck, Fern Raper, and Amy and Seth Ruskin. And I thank Les Wallach and Henry Tom at Line and Space, LLC, for giving me so many opportunities to think about space in a different way. Others who are far from Tucson but who have remained close to my heart include my grandmother, Vivian $M^{c}$ Gaghie, and my true comrade-in-arms, Cristina Perez.

I am grateful for the financial support of the National Science Foundation through the Graduate Student Research Fellowship and the Zonta Foundation through the Amelia Earhart Fellowship.

## Table of Contents

List of Figures ..... 10
List of Tables ..... 13
Abstract ..... 14
Chapter 1. Introduction ..... 16
1.1. Organization of the Dissertation ..... 18
1.2. The Evolution of the Ly- $\alpha$ forest ..... 19
1.3. The Proximity Effect and the Ultraviolet Background ..... 20
1.4. Simulations of Ly- $\alpha$ Forest Spectra and the Proxmity Effect ..... 22
1.5. Conclusions ..... 23
Chapter 2. MMT Data and Absorption Line Statistics at $Z>1.7$ ..... 25
2.1. Observations and Data Reduction ..... 25
2.2. Line Identification Process ..... 26
2.3. Results and Discussion ..... 29
Chapter 3. The Ultraviolet Background at $Z>1.7$ ..... 56
3.1. Data ..... 56
3.1.1. Spectrophotometry ..... 56
3.1.2. QSO Systemic Redshifts ..... 57
3.2. Ly- $\alpha$ Forest Statistics for $z_{a b s} \approx z_{e m}$ : The Proximity Effect ..... 58
3.2.1. Spectrophotometry ..... 58
3.2.2. Number of Lines with $z_{a b s} \approx z_{e m}$ ..... 59
3.2.3. Photoionization Model ..... 60
3.2.4. Maximum Likelihood Analysis ..... 62
3.2.5. Systemic QSO Redshifts ..... 65
3.2.6. The HI Ionization Rate ..... 68
3.3. Simulations and the Curve of Growth ..... 69
3.4. Results and Discussion ..... 71
3.4.1. HI Ionization Rate ..... 74
3.4.2. Curve-of-Growth and Other Systematics ..... 74
3.4.3. Comparison with Previous Measurements ..... 76
3.4.4. Comparison with Models for the Background ..... 78
Table of Contents-Continued
Chapter 4. HST/FOS Data and the Ultraviolet Background at $Z<1.7$ ..... 119
4.1. Data Sample ..... 119
4.2. Systemic Redshifts ..... 119
4.2.1. Observations ..... 120
4.2.2. Measurements ..... 121
4.3. Lyman Limit Fluxes ..... 121
4.4. Analysis ..... 122
4.5. Results ..... 125
4.5.1. Simulations ..... 129
4.5.2. HI Ionization Rate ..... 131
4.5.3. Variable Equivalent Width Threshold ..... 132
4.6. Discussion ..... 134
4.6.1. Radio Loudness ..... 134
4.6.2. Non-Zero $\Omega_{\Lambda}$ ..... 135
4.6.3. $\quad d \mathcal{N} / d z$ ..... 136
4.6.4. Comparison with Previous Results ..... 138
4.6.5. Comparison with Models ..... 140
4.6.6. Systematics ..... 141
4.7. Summary ..... 143
Chapter 5. Lognormal Models of the Proximity Effect in Quasar Spectra ..... 188
5.1. The Lyman $\alpha$ Forest ..... 188
5.1.1. The Density and Velocity Fields ..... 188
5.1.2. Comparison with N -body simulations ..... 189
5.1.3. Physical Conditions in the Absorbing Gas ..... 190
5.1.4. Comparison with hydrodynamical simulations ..... 193
5.1.5. The Background Ly- $\alpha$ Forest Model ..... 196
5.2. The Proximity Effect ..... 200
5.2.1. QSO Radiation Field ..... 201
5.2.2. Clustering Near Quasars ..... 202
5.2 .3 . The Spectral Signature of the Proximity Effect ..... 204
5.2.4. Measurement of the Ionizing Background ..... 207
5.2.5. Quasar Systemic Redshifts ..... 209
5.3. Summary and Future Work ..... 211
5.3.1. Measurement of UV Background from Mean Flux ..... 215
Appendix A. Figure 2.2 (Continued) ..... 249

## Table of Contents-Continued

## Appendix B. Line Lists and Identifications for MMT QSO Spectra269

Appendix C. Notes on Individual MMT Objects ..... 357
C.1. Q 0006+020 $z_{e m}=2.340$ ..... 357
C.2. Q 0027+014 $z_{\text {em }}=2.310$ ..... 358
C.3. Q 0037-018 $z_{e m}=2.341$ ..... 359
C.4. Q 0049+007 $z_{e m}=2.279$ ..... 360
C.5. Q 0123+257 $z_{e m}=2.370$ ..... 361
C.6. Q 0150-203 $z_{e m}=2.148$ ..... 362
C.7. Q 0153+744 $z_{e m}=2.341$ ..... 364
C.8. Q 0226-038 $z_{e m}=2.073$ ..... 365
C.9. Q 0348+061 $z_{e m}=2.056$ ..... 366
C.10.Q 0400+258 $z_{\text {em }}=2.108$ ..... 367
C.11.Q 0747+610 $z_{e m}=2.491$ ..... 368
C.12.Q 0836+710 $z_{e m}=2.218$ ..... 371
C.13.Q 0848+153 $z_{\text {em }}=2.014$ ..... 372
C.14.Q 0936+368 $z_{e m}=2.025$ ..... 372
C.15.Q 0952+335 $z_{e m}=2.504$ ..... 372
C.16.Q 0955+472 $z_{e m}=2.482$ ..... 374
C.17.Q 0956+122 $z_{e m}=3.308$ ..... 375
C.18.Q 1009+299 $z_{e m}=2.633$ ..... 378
C.19.Q 1207+399 $z_{e m}=2.459$ ..... 379
C.20.Q 1210+175 $z_{e m}=2.564$ ..... 379
C.21.Q 1231+294 $z_{e m}=2.018$ ..... 380
C.22.Q 1323-107 $z_{e m}=2.360$ ..... 381
C.23.Q 1329+412 $z_{e m}=1.934$ ..... 382
C.24.Q 1337+285$z_{e m}=2.541$384
C.25.Q 1346-036 $z_{\text {em }}=2.362$ ..... 384
C.26.Q 1358+115$z_{\text {em }}=2.589$385
C.27.Q $1406+492$$z_{\text {em }}=2.161$386
C.28.Q 1408+009$z_{\text {em }}=2.260$387
C.29.Q $1421+330$ $z_{e m}=1.905$ ..... 387C.30.Q 1422+231C.31.Q $1435+638$C.32.Q 1604+290
C.33.Q 1715+535
C.34.Q 2134+004
C.35.Q 2251+244
$z_{\text {em }}=3.623$ ..... 389
$z_{\text {em }}=2.066$ ..... 391
$z_{\text {em }}=1.962$ ..... 392
$z_{\text {ern }}=1.932$ ..... 392
C.36.Q 2254+024$z_{e m}=1.941$394
$z_{\mathrm{em}}=2.359$ ..... 394
C.37.Q 2310+385 $z_{e m}=2.181$ ..... 397$z_{\text {em }}=2.090$396

## Table of Contents-Continued

C.38.Q 2320+079 $z_{e m}=2.088$ ..... 397
C.39.Q 2329-020 $z_{e m}=1.896$ ..... 398
C.40.Data from the Literature ..... 398
Appendix D. Figure 4.4 (Continued) ..... 399
References ..... 436

## List of Figures

Figure 2.1. FWHM versus wavelength for MMT/Blue Channel spectra ..... 47
Figure 2.2. MMT/Blue Channel spectra ..... 48
Figure 2.3. Redshift histograms, MMT data ..... 49
Figure 2.4. $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ for $z<2.5$ ..... 50
FIGURE 2.5. $\quad\left(\gamma_{\text {FINDSL }}-\gamma_{\text {simulation }}\right) / \sigma_{\gamma}$ versus Signal-to-Noise ratio ..... 51
Figure 2.6. Histograms of line distributions ..... 52
Figure 2.7. $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$, data resolution, data $S / N$ ..... 53
Figure 2.8. $\log (d \mathcal{N} / d z)$ versus $\log (1+z), 0.16 \AA<W<0.32 \AA$ ..... 54
Figure 2.9. Rest equivalent width distributions ..... 55
Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs ..... 96
Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued) ..... 97
Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued) ..... 98
Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued) ..... 99
Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued) ..... 100
Figure 3.2. Infrared spectra of $z \approx 2$ QSOs ..... 101
Figure 3.2. Infrared spectra of $\mathrm{z} \approx 2$ QSOs (Continued) ..... 102
Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued) ..... 103
Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued) ..... 104
Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued) ..... 105
Figure 3.3. Lyman limit luminosity versus redshift for $z \approx 2$ QSOs ..... 106
Figure 3.4. Proximity effect line deficit ..... 107
Figure 3.5. $\chi^{2}$ of binned data with respect to the ionization model ..... 108
Figure 3.6. Number of lines per coevolving redshift coordinate versus $\omega$, BDO 1 ..... 109
Figure 3.7. Likelihood function versus $\log \left[\mathrm{J}\left(\nu_{0}\right)\right]$ ..... 110
Figure 3.8. Number of lines per coevolving redshift coordinate versus $\omega$, max- imum likelihood ..... 111
Figure 3.9. Emission line redshift difference histograms ..... 112
Figure 3.10. Sample simulation spectra ..... 113
Figure 3.10. Sample simulation spectra (Continued) ..... 114
Figure 3.11. Number of lines per coevolving redshift coordinate versus $\omega$, sim- ulations ..... 115
Figure 3.12. Curve of growth effects ..... 116
Figure 3.13. $\log \left[\mathrm{J}\left(\nu_{0}\right)\right]$ versus redshift ..... 117
Figure 3.14. Power law fits to $\log \left[\mathrm{J}\left(\nu_{0}\right)\right]$ versus redshift ..... 118
Figure 4.1. Histograms of HST/FOS QSO and absorption line redshifts ..... 167
Figure 4.2. Emission line spectra of HST/FOS QSOs ..... 168
Figure 4.2. Emission line spectra of HST/FOS QSOs (Continued) ..... 169

## List of Figures-Continued

Figure 4.2. Emission line spectra of HST/FOS QSOs (Continued) ..... 170
Figure 4.2. Emission line spectra of HST/FOS QSOs (Continued) ..... 171
Figure 4.3. Histograms of redshift differences for HST/FOS QSOs ..... 172
Figure 4.4. HST/FOS spectra used to measure QSO Lyman limit fluxes ..... 173
Figure 4.5. Lyman limit luminosity versus redshift for objects in HST/FOS and MMT samples ..... 174
Figure 4.6. Proximity Effect Line Deficits for HST/FOS QSOs ..... 175
Figure 4.7. $\chi^{2}$ of binned absorption line data with respect to ionization model for HST/FOS QSOs ..... 176
Figure 4.8. Number of lines per coevolving redshift coordinate versus $\omega$, BDO ..... 177
Figure 4.9. Likelihood function versus $\log \left[\mathrm{J}\left(\nu_{0}\right)\right]$ for HST/FOS sample ..... 178
Figure 4.10. Number of lines per coevolving redshift coordinate versus $\omega$, max- imum likelihood ..... 179
Figure 4.11. $\log \left[J\left(\nu_{0}\right)\right]$ versus redshift ..... 180
Figure 4.12. $\log \left[\mathrm{J}\left(\nu_{0}\right)\right]$ recovered from simulated QSO spectra ..... 181
Figure 4.13. HI ionization rate versus redshift ..... 182
Figure 4.14. Histogram of jackknife measurements of HI ionization rate at $Z<1.7$ ..... 183
Figure 4.15. Radio loudness of QSOs in HST/FOS sample ..... 184
Figure 4.16. $\log \left[J\left(\nu_{0}\right)\right]$ versus redshift ..... 185
Figure 4.17. $d \mathcal{N} / d z$ versus redshift ..... 186
Figure 4.18. $d \mathcal{N} / d z$ and $\Gamma$ versus redshift ..... 187
Figure 5.1. N-body and LN dark matter density distributions ..... 230
Figure 5.2. Cumulative flux decrement distributions for Keck data and LN simulations ..... 231
Figure 5.3. Cumulative flux decrement distributions for SPH and LN simu- lations ..... 232
Figure 5.4. Distributions of hydrogen neutral fraction, HI optical depth, and hydrogen densities for SPH simulations and LN simulations ..... 233
Figure 5.5. Cumulative flux decrement distributions for Keck data and MMT data ..... 234
Figure 5.6. Histogram of mean decrements in simulated spectra ..... 235
Figure 5.7. Differential flux distribution of pixels in the MMT data and LN simulations ..... 236
Figure 5.8. Data and simulated spectra ..... 237
Figure 5.9. Redshift distribution of absorption lines in data and simulated spectra ..... 238
Figure 5.10. Histograms of $\gamma$ in simulations ..... 239

## List of Figures—Continued

Figure 5.11. Comparison of differential flux distributions for random and high density simulations ..... 240
Figure 5.12. Mean flux in $100 \AA$ bins as a function of redshift ..... 241
Figure 5.13. Deficit of absorption lines as a function of luminosity distance from QSOs ..... 242
Figure 5.14. Histogram of 0.32 Aline deficits within $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ ..... 243
Figure 5.15. Histogram of 0.16 Åline deficits within $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ ..... 244
Figure 5.16. Maximum likelihood values of $\Gamma$ and HM96 scaling factor ..... 245
Figure 5.17. Histograms of $\log (\Gamma)$ and $f_{\Gamma}$ ..... 246
Figure 5.18. Histogram $\log (\Gamma)$ from ten realizations of the systemic redshift transformation ..... 247
Figure 5.19. Mean flux in $50 \AA$ bins as a function of $\omega$ ..... 248

## List of Tables

Table 2.1. Summary of $z \approx 2$ QSO Observations ..... 40
Table 2.2. QSO Spectra from the Literature ..... 42
Table 2.3. Maximum Likelihood Estimations of $\gamma, W^{*}$, and $\mathcal{A}_{0}$ ..... 44
Table 2.4. Simulation Results for $\gamma$ ..... 45
Table 3.1. Spectrophotometry Observations of $z \approx 2$ QSOs ..... 82
Table 3.2. Summary of Narrow Emission Line Observations of $z \approx 2$ QSOs ..... 83
Table 3.3. Spectrophotometric Properties of $z \approx 2$ QSOs ..... 84
Table 3.4. Measurements of $J\left(\nu_{0}\right)$ at $z \approx 2$ ..... 87
Table 3.5. Emission Line Redshifts for $z \approx 2$ QSOs ..... 89
Table 3.6. Ionization Rates ..... 94
Table 3.7. Simulation Results ..... 94
Table 3.8. Literature Proximity Effect Measurements of $J\left(\nu_{0}\right)$ ..... 95
Table 4.1. HST/FOS Sample QSOs and Emission Line Redshifts ..... 146
Table 4.2. Emission Line Observations of HST/FOS QSOs ..... 154
Table 4.3. Spectrophotometric Properties of HST/FOS QSOs ..... 155
Table 4.4. Measurements of $J\left(\nu_{0}\right)$ at $Z<1.7$ ..... 163
Table 4.5. Simulation Results ..... 165
Table 4.6. HI Ionization Rates ..... 166
Table 5.1. Mean Flux Decrements in Simulated Spectra ..... 219
Table 5.2. Line Statistics in Simulated Spectra ..... 222
Table 5.3. Mean Ly- $\alpha$ Optical Depth versus Redshift in Simulated Spectra ..... 226
Table 5.4. Ionization Rates and HM96 Scaling Factors ..... 228
Table 5.5. Ionization Rates after Redshift Transformation ..... 229
Table B.1. MMT Line Lists and Identifications ..... 270

## Abstract

I present moderate resolution spectra for 39 Quasi-Stellar Objects (QSOs) at $z \approx 2$ obtained at the Multiple Mirror Telescope (MMT). These are combined with spectra of comparable resolution of 60 QSOs from the literature with $z>1.7$ to investigate the distribution of Lyman $\alpha$ ( $\mathrm{Ly}-\alpha$ ) forest absorption lines in redshift and equivalent width. I find $\gamma=1.88 \pm 0.22$ for lines stronger than a rest equivalent width of $0.32 \AA$, where $\gamma$ is the line redshift distribution parameter, in good agreement with some previous studies. These spectra are used to measure $J\left(\nu_{0}\right)$, the mean intensity of the extragalactic background radiation at the Lyman limit, using the proximity effect signature. I find $J\left(\nu_{0}\right)=7.0_{-4.4}^{+3.4} \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ at $1.7<z<3.8$.

A sample of 151 QSO spectra from the Faint Object Spectrograph on the Hubble Space Telescope are used to measure $J\left(\nu_{0}\right)$ at low redshift. I find $J\left(\nu_{0}\right)=6.5_{-1.6}^{+38 .} \times$ $10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ at $z<1$, and $J\left(\nu_{0}\right)=1.0_{-0.2}^{+3.8} \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2}$ $\mathrm{Hz}^{-1} \mathrm{sr}^{-1}$ at $z>1$, indicating that $J\left(\nu_{0}\right)$ is evolving over $0.03<z<3.8$. This work confirms that the evolution of the number density of Ly- $\alpha$ lines is driven by a decrease in the ionizing background from $z \sim 2$ to $z \sim 0$ as well as by the growth of structure in the intergalactic medium and the formation of galaxies from intergalactic gas. These measurements of $J\left(\nu_{0}\right)$ are in reasonable agreement with the predictions of models based on the integrated quasar luminosity function.

I present simulated $\mathrm{Ly}-\alpha$ forest spectra created using the lognormal approximation to the linear and mildly non-linear evolution of the density and velocity fields. The model spectra give a mean Ly- $\alpha$ forest flux decrement of 0.128 at $\langle z\rangle=2.07$, while the MMT data show $<\mathrm{D}>=0.129$. The photoionization effects of quasars placed in the simulated density fields on the surrounding intergalactic medium are incorporated into the synthetic spectra. This reasonably reproduces the proximity effect signature seen in the data, a $2-3 \sigma$ deficit of absorption lines within $2 h^{-1} \mathrm{Mpc}$ of quasars. I
find that maximum likelihood methods reliably estimate the ionization rate from the UV background radiation if quasars do not preferentially occupy regions of high overdensity. I analyze the extent to which the clustering of mass around quasars and uncertainty in quasar redshifts will bias the measurement of the ionizing background. In both cases, the ionization rates are overestimated by a factor of $\sim 3$.

## Chapter 1

## Introduction

Since their postulation (Bahcall \& Salpeter 1965), discovery (Lynds 1971), and first characterization (Sargent et al. 1980, Weymann, Carswell, \& Smith 1981), Lyman- $\alpha$ (Ly- $\alpha$ ) absorption lines in the spectra of high redshift quasi-stellar objects (QSOs, or quasars), collectively referred to as the Ly- $\alpha$ forest, have been used to probe the physical conditions in the intergalactic medium (IGM), a significant reservoir of baryons throughout the history of the universe.

Both observations and theoretical calculations have shown that most of this absorption can be attributed to neutral hydrogen in galaxies and large-scale structure along the line of sight (Lanzetta et al. 1995,1996, Stocke et al. 1995, Shull, Stocke, \& Penton 1996, Bi \& Davidsen 1997, Chen et al. 1998, Ortiz-Gil et al. 1999, Impey, Petry, \& Flint 1999, Shull, Penton, \& Stocke 1999, Penton, Stocke, \& Shull 2002). In particular, hydrodynamical models of structure formation in the expanding universe (Cen et al. 1994, Zhang, Anninos, \& Norman 1995, Hernquist et al. 1996, MiraldaEscudé et al. 1996, Theuns et al. 1998a,b, Zhang et al. 1998, Davé et al. 1999, Bryan et al. 1999) have led to a dramatic shift in the conceptual picture of the Ly- $\alpha$ forest. The absorbing structures, once modeled as isolated systems of primordial gas, either freely expanding or bound by pressure or cold dark matter mini-halos, are now thought to arise from a continuous, spatially fluctuating density field within the larger context of hierarchical structure formation.

In models of Ly- $\alpha$ absorbers, they are in photoionization equilibrium with a background radiation field. This background field is treated as uniform on large scales, and this assumption is warranted given the expected "outside-in" progression of hydrogen reionization from underdense to overdense regions. (Miralda-Escudé, Haehnelt,
\& Rees 2000). The total length of the reionization epoch depends on the number and characteristic luminosity of the ionizing sources, but given the lack of observed Gunn-Peterson absorption at $z \lesssim 6.2$ (Becker et al. 2001, Djorgovski et al. 2001) the premise of a uniform background radiation field at $z<4$ is justified.

The most detailed models of the background in the ultraviolet (UV) at high redshift have calculated the integrated emission from the known QSO population and incorporated the effects of reprocessing in an inhomogeneous intergalactic medium (Haardt \& Madau 1996, hereafter HM96, Fardal, Giroux, \& Shull 1998). High redshift galaxies have been detected through Ly- $\alpha$ emission (Hu \& McMahon 1996, Cowie \& Hu 1998, Hu, Cowie, \& M ${ }^{c}$ Mahon 1998, Pascarelle, Windhorst, \& Keel 1998, Thommes et al. 1998, Hu, Mc Mahon, \& Cowie 1999, Kudritzki et al. 2000, Rhoads et al. 2000, Steidel et al. 2000) and through the Lyman dropout technique and subsequent follow-up spectroscopic observations (Steidel et al. 1996a,b, Madau et al. 1996, Lowenthal et al. 1997). Star formation in galaxies has been considered as a source of the UV background in addition to quasars (Madau \& Shull 1996, Shull et al. 1999, Haehnelt et al. 2001, Bianchi, Cristiani, \& Kim 2001), especially in light of recent observations of Lyman continuum emission in a composite spectrum of 29 Lyman break galaxies at a mean redshift of 3.4 (Steidel, Pettini, \& Adelberger 2001). The contribution from these systems is potentially a few times larger than that of quasars at $z \gtrsim 3.5$ (Madau, Haardt, \& Rees 1999, Bianchi, Cristiani, \& Kim 2001), though observations of two Lyman break galaxies with Ly- $\alpha$ equivalent widths more typical of the full $z \sim 3$ spectroscopically selected galaxy sample indicate that escape fractions of these systems at these redshifts may in fact be quite low (Giallongo et al. 2002).

The phenomenon known as the proximity effect refers to a deficit of Ly- $\alpha$ absorption lines in a quasar spectrum near the quasar emission line. This has been interpreted to be the result of enhanced photoionization of neutral hydrogen in the vicinity of the quasar generated by the quasar's own UV emission (Weymann, Car-
swell, \& Smith 1981, Murdoch et al. 1986). The balance between the strength of the background UV radiation field, which mitigates the line density in the global Ly- $\alpha$ forest, and the local quasar radiation field, permits an estimate of the mean intensity of the ambient background at the Lyman limit of hydrogen (Carswell et al. 1987, Bajtlik, Duncan, \& Ostriker 1988, hereafter BDO).

### 1.1 Organization of the Dissertation

In this dissertation, I present a large sample of QSO spectra and use the proximity effect to measure the mean intensity of the metagalactic UV background radiation field from early cosmic epochs at which the universe was approximately $10 \%$ of its present age to the present time. These chapters have appeared as papers in the Astrophysical Journal as part a series entitled "A Uniform Analysis of the Ly- $\alpha$ Forest at $z=0-5$." In this series, my collaborators and I have sought to characterize the evolution of the neutral hydrogen content of the universe and the ambient UV radiation field over this redshift range using QSO spectra. The wavelength regions of interest lie in the rest frame UV part of the electromagnetic spectrum. Distant, high-redshift quasars can thus be observed using ground-based telescopes as the UV is redshifted into the observed optical. Low-redshift objects, however, must be observed from space due to the high UV opacity of Earth's atmosphere. The high- and low-redshift data used in this dissertation were obtained from the Multiple Mirror Telescope (MMT) on Mt. Hopkins in Arizona and the Hubble Space Telescope (HST), respectively. In Chapter 2, Paper I in the Astrophysical Journal series (Scott et al. 2000a), I present the MMT data and analyze the statistics of the Ly- $\alpha$ absorption line distribution at high redshift, $z>1.7$. In Chapter 3, Paper II of the series (Scott et al. 2000b), I use these data to measure the intensity of the UV background radiation field at high redshift. In Chapter 4, Paper V in the series (Scott et al. 2002), I present a measurement of this intensity at low redshift $(z<1.7)$ from the HST data. The papers presented as
chapters in this dissertation have been modified slightly to make them more cohesive than they would be if the papers simply appeared in their published forms. Papers III and IV in the series are not represented as chapters in this dissertation and present the HST/FOS data sample (Bechtold et al. 2002) and analyze the distribution and clustering of absorbers at low redshift (Dobrzycki et al. 2002), respectively. The final chapter of the dissertation, Chapter 5, investigates the theoretical basis for the proximity effect phenomenon observed in the high redshift MMT data presented in the Chapter 2.

### 1.2 The Evolution of the Ly- $\alpha$ forest

Much recent work has promoted treating the Ly- $\alpha$ forest as spatial fluctuations in the continuous density field of the intergalactic medium ( Bi 1993 , Reisenegger \& MiraldaEscudé 1995, Hernquist et al. 1996, Miralda-Escudé et al. 1996, Bi \& Davidsen 1997, Croft et al. 1998,1999, Weinberg et al. 1998). In this work, however, I will continue to interpret the Ly- $\alpha$ forest as a series of discrete lines for comparison to previous work.

The redshift distribution of Ly- $\alpha$ forest lines can be described by a power law: $d \mathcal{N} / d z=\mathcal{A}_{0}(1+z)^{\gamma}$ (Sargent et al. 1980, Weymann, Carswell, \& Smith 1981, Young et al. 1982, Murdoch et al. 1986). Several authors have carried out the analysis of the statistics of the Ly- $\alpha$ forest at high redshift (Lu, Wolfe, \& Turnshek 1991, hereafter LWT, Bechtold 1994, hereafter B94, Williger et al. 1994, Cristiani et al. 1995, Giallongo et al. 1996, Kim et al. 1997). Hubble Space Telescope observations of the low redshift Ly- $\alpha$ forest (Bahcall et al. 1993, 1996, Weymann et al. 1998, Dobrzycki et al. 2002) indicate that this evolution is significantly flatter at redshifts less than 1.7.

In Chapter 2, a homogeneous sample of moderate resolution spectra of QSOs at $z=1.7-4.1$ is used to investigate the number density evolution of Ly- $\alpha$ systems
and how this changes with redshift and with varying equivalent width thresholds. Specifically, the Ly- $\alpha$ forest in the redshift range between 1.7 and 2.0 was targeted because few lines of sight in the literature cover this range, as it extends down to wavelengths of $\sim 3200 \AA$. Improvements in CCD technology allowed us to obtain data in this spectral region. I present new data for 39 objects and supplement this sample with 60 objects from the literature. Metal line systems in these spectra are identified and removed from the final analysis of the Ly- $\alpha$ forest (Murdoch et al. 1986, hereafter MHPB). The resulting Ly- $\alpha$ absorption line sample is comprised of 2079 lines in the range $1.7<z<4.1$ when a variable equivalent width threshold is used, or 1131 lines using a fixed rest equivalent width threshold of $0.32 \AA$.

### 1.3 The Proximity Effect and the Ultraviolet Background

The number density evolution of Ly- $\alpha$ absorbers in an individual QSO spectrum departs from the basic power law trend near the Ly- $\alpha$ emission line such that the line density decreases with proximity to the QSO emission redshift (Weymann, Carswell, \& Smith 1981, Murdoch et al. 1986). As stated above, the simplest explanation for this proximity effect is enhanced ionization of HI in the vicinity of the QSO by UV photons from the QSO itself. This interpretation, along with the assumptions about the spectrum of the background and the photoionization of the nearby IGM by the QSOs, allows for a measurement of the mean intensity of the ionizing background at the Lyman limit of hydrogen (Carswell et al. 1987, BDO), denoted $J\left(\nu_{0}\right)$. These measurements are compared to estimates of the integrated emission from quasars and star-forming galaxies. The proximity effect measurement of $J\left(\nu_{0}\right)$ at $z=1.7-4.1$ from the MMT data is presented in Chapter 3. The measured UV background at these redshifts is found to be consistent with the expected contribution from the known population of quasars, albeit to within somewhat large uncertainties.

The decline of the quasar space density from $z \sim 2$ to the present (eg. Boyle
et al. 2000) is expected to drive a corresponding decline in the intensity of the UV background. Hydrodynamic simulations of the low redshift IGM (Theuns et al. 1998, Davé et al. 1999) indicate that the evolution of the ionizing background is the primary driver behind the flattening of the redshift distribution of Ly- $\alpha$ lines at $z<1.7$. The growth of structure pulling gas from low density regions into high density regions also contributes to this and other attributes of the evolution of the Ly- $\alpha$ forest. The only previous measurement of the UV background at $z<1.7$ (Kulkarni \& Fall 1993) was based upon a sample of 13 QSOs and fewer than 100 lines, and has correspondingly large error bars. Given the importance of the value of the HI ionization rate to the hydrodynamical evolution of the low redshift universe, performing this measurement with a much larger line sample is worthwhile. I address this question in Chapter 4 by using 151 of the QSO spectra from the HST/FOS archives.

The spectra comprising the MMT and HST/FOS datasets are of moderate resolution, $\sim 1 \AA$ FWHM. In this work, high spectral resolution was sacrificed for the sake of obtaining spectra of many objects, because the proximity effect analysis requires good absorption line statistics and therefore many QSO sight lines. This is difficult to achieve at high resolution, the primary reason for using a large set of moderate resolution spectra such as the one presented here. The full MMT and HST/FOS archival data sets are available online at
http://lithops.as.arizona.edu/ॅjill/QuasarSpectra or
http://hea-www.harvard.edu/QEDT/QuasarSpectra.
Several possible systematic effects that may bias the proximity effect analysis are discussed in Chapters 3 and 4. One important systematic effect is uncertainty in the systemic redshifts of the QSOs. Redshifts measured from low ionization permitted lines (e.g. Balmer lines or Mg II) or forbidden lines (e.g. [OIII] $\lambda \lambda 4959,5007$ ) lines have been shown to be redshifted with respect to Ly- $\alpha$ and C IV emission by up to $\sim 250 \mathrm{~km} \mathrm{~s}^{-1}$ (Boroson \& Green 1992, Laor et al. 1995). B94 found that increasing the values of the QSO redshifts by $1000 \mathrm{~km} \mathrm{~s}^{-1}$ caused the best fit value of $J\left(\nu_{0}\right)$ to
be decreased by a factor of 3 . I therefore obtained emission line spectra for several objects in both the high redshift and low redshift QSO samples in order to examine redshift differences between Ly- $\alpha$ and [OIII] $\lambda \lambda 4959,5007, \mathrm{Mg}$ II or Balmer emission. In Chapters 3 and 4, I investigate the effect of these shifts on the value of $J\left(\nu_{0}\right)$ derived at $z>1.7$ and $z<1.7$, respectively.

The results of all of the work done to measure the UV background are summarized in Chapter 3 and again in Chapter 4 and are in general agreement with the predictions of models of the UV background which integrate the contribution from known population of quasars and include reprocessing effects in an inhomogeneous intergalactic medium (HM96, Fardal, Giroux, \& Shull 1998).

### 1.4 Simulations of Ly- $\alpha$ Forest Spectra and the Proxmity Effect

In Chapter 5, I present a large sample of theoretical QSO spectra to compare with the MMT data presented in Chapter 2, specifically to investigate the quasar photoionization model for the proximity effect signature. These theoretical spectra were created using the lognormal approximation, a technique outlined by Bi \& Davidsen (1997, BD97 hereafter). The lognormal approximation allows one to construct density and peculiar velocity fields in the linear and mildly nonlinear regimes relevant to the Ly- $\alpha$ forest from Gaussian random fields under a lognormal transformation. The lognormal transformation is applied to ensure a non-negative density field at all points, and is mathematically motivated by its simple and smooth connection of the linear behavior of fluctuations at early times and on large scales and isothermal hydrostatic equilibrium on small scales (BD97, Coles \& Jones 1991). Gas temperatures are assigned to density points by employing an IGM "equation of state", and the neutral fraction of hydrogen at each point is calculated assuming photoionization equilibrium. The neutral fraction and peculiar velocity at a given point are in turn used to calculate
the optical depth.
The relative simplicity of the lognormal models is advantageous in that the low computational expense allows for the creation of a large number of independent model realizations at many redshifts over long lines of sight. This is particularly important for obtaining good statistics on the Ly- $\alpha$ forest and the deviations from those statistics due to the proximity effect, and this is the primary reason for using the lognormal model rather than results from detailed hydrodynamic simulations.

To simulate the proximity effect, quasars are placed in the simulated density fields and their UV fluxes are included in the ionization balance of the IGM. I use these models to investigate various systematics that may enter into the analysis of the proximity effect to measure the ambient metagalactic UV background, particularly the effects of clustering of matter around quasars and uncertainties in quasar systemic redshifts.

### 1.5 Conclusions

The primary results of this work are as follows: Proximity effect measurements confirm the evolution in the UV background from $z \sim 2$ to the present epoch that is expected due to the decline in the quasar space density in this redshift range. The measured mean intensity of the background is a factor of $\sim 10$ lower at $z \sim 0.5$ than at $z \sim 2.5$, though it must be noted that the uncertainties in the proximity effect measurements, particularly at low redshift, are at present large enough that they must be interpreted as a tentative observational corroboration of the models of the UV background. From comparisons with these models, I find that the integrated UV emission from the quasar population can account for the observed UV background, given the measurement uncertainties. No significant contribution from star-forming galaxies is required to explain the observed $J\left(\nu_{0}\right)$ at $z \lesssim 4$. I present the first measurement of $J\left(\nu_{0}\right)$ in the redshift range $z=1-1.7$, the range over which the redshift distribution
of $\mathrm{Ly}-\alpha$ absorbers flattens significantly from a steeper power law at $z \gtrsim 1.7$. Though detailed simulations by other authors show that the decline in the UV background with decreasing redshift at $z<1.7$ is the primary reason for the flattening, the measured value of $J\left(\nu_{0}\right)$ presented in this work indicates that the evolution of structure in the IGM must also contribute to the observed $d \mathcal{N} / d z$ in the Ly- $\alpha$ forest.

The lognormal models of the Ly- $\alpha$ forest and proximity effect demonstrate that quasar photoionization can reasonably produce the observed proximity effect signature. The techniques used to derive $J\left(\nu_{0}\right)$ from the proximity effect are found to be reliable if systematic effects caused by uncertainties in quasar systemic redshifts are properly considered and if quasars do not preferentially inhabit regions of significant overdensity in the underlying IGM density distribution.

## Chapter 2

## MMT Data and Absorption Line Statistics at $Z>1.7$

### 2.1 Observations and Data Reduction

A sample of 39 QSOs was observed using the Multiple Mirror Telescope and Blue Channel Spectrograph. The observations are summarized in Table 2.1. Each object's redshift is given in column (3) and the reference for that redshift is given in column (4).

The three instrumental setups used are as follows: (1) the "Big Blue" image tube and photon counting Reticon detector, a $832 \mathrm{I} \mathrm{mm}^{-1}$ grating blazed at $3900 \AA$ in the second order with a $\mathrm{CuSO}_{4}$ red blocking filter, and a $1^{\prime \prime} \times 3^{\prime \prime}$ slit; (2) the $3 \mathrm{~K} \times 1 \mathrm{KCCD}$, the $8321 \mathrm{~mm}^{-1}$ grating blazed at $3900 \AA$ in the second order with a $\mathrm{CuSO}_{4}$ order blocking filter, and a $1^{\prime \prime} \times 180^{\prime \prime}$ slit; and (3) the $3 \mathrm{~K} \times 1 \mathrm{~K} \mathrm{CCD}$, $8001 \mathrm{~mm}^{-1}$ grating blazed at $4050 \AA$ in the first order, and a $1^{\prime \prime} \times 180^{\prime \prime}$ slit. All these spectra have a spectral resolution of $\sim 1 \AA$ with the exception of the spectra of $1207+399$ and $1408+009$ taken with the $800 \mathrm{I} \mathrm{mm}^{-1}$ grating, which have a resolution of $\sim 2.5 \AA$. Thinning and backside illumination of a Loral CCD along with the use of antireflection coatings and backside surface charging (Lesser 1994) improved the quantum efficiency of the $3 \mathrm{~K} \times 1 \mathrm{~K}$ CCD used to over $80 \%$ at $3200 \AA$. The exposures from the first runs using the improved CCD at the MMT suffer from a variable focus across the chip due to problems with the original field flatteners used. Figure 2.1 shows the FWHM of the comparison lamp lines as a function of wavelength. The July 1993 data was taken on the first run with this CCD detector; and a number of problems were encountered, including poor charge transfer efficiency and a jump in the bias level of $\sim 8 \mathrm{ADU}$ in the center of the chip. On this run, the FWHM rises to
$\sim 2.5 \AA$ at the red end of the spectrum (short-dashed line in Figure 2.1).
Wavelength calibration was performed using $\mathrm{He}-\mathrm{Ne}-\mathrm{Ar}-\mathrm{Hg}-\mathrm{Cd}$ lamp exposures; and domeflats or quartz exposurers were used to correct for pixel-to-pixel variations. When available, a few half-hour exposures of each object are combined; and the total integration time is listed in Table 2.1. An example QSO spectrum is shown in Figure 2.2. The remainder can be found in Appendix A.

Cosmic rays were removed from the data during the reduction process. Bad columns on the CCD were left in the spectrum in order to keep track of their positions. The flux in these regions was set to a value of -1000.; and they were excluded from the analysis. In some spectra, some clearly non-Gaussian features are present at the red end, mainly redward of Lyman $\alpha$ emission. Because these features occur at the same pixel in each of the spectra in which they are visible, they are identified as traps in the CCD. They are discussed individually in Appendix C below.

### 2.2 Line Identification Process

The continuum was fit iteratively to each spectrum and significant ( $3 \sigma$ or greater) absorption lines were found by measuring the equivalent width in bins of size equal to 2.46 times the FWHM of the comparison lines in pixels, the point at which a Gaussian is $1.5 \%$ of its peak value (B94, Young et al. 1979). Lines of $3 \sigma$ significance and above were used to help identify metal line systems, but only lines of greater than $5 \sigma$ significance were used in the analysis of the Lyman $\alpha$ forest statistics.

Using the technique described in Dobrzycki and Bechtold (1996), we produced a set of 30 simulated $z=2.48$ pure $\mathrm{Ly}-\alpha$ forest spectra in order to determine how reliably our program for finding significant lines, FINDSL, recovers those generated by the simulations. We use values of 1.82 and 1.46 for $\mathrm{Ly}-\alpha$ forest statistics $\gamma$ and $\beta$, but the results of this analysis should not be sensitive to the value of $\gamma$ as the redshift path covered in each spectrum is small. The lower and upper column density limits
chosen were $10^{12}$ and $7 \times 10^{14} \mathrm{~cm}^{-2}$ respectively; and the mean Doppler parameter and width of the Doppler parameter distribution used were $28 \mathrm{~km} \mathrm{~s}^{-1}$ and 10 km $\mathrm{s}^{-1}$. The column density limits were chosen to give the same total absorption in the simulated spectra as is seen in the spectrum of $0955+472$, the object spectrum which served as the template for this series of simulations.

We determine matches between the simulation line list output and the FINDSL line lists on the basis of the best wavelength match between simulated and recovered lines. At $5 \sigma$ significance, the line lists are $55 \%$ complete. When blending is accounted for by matching all simulated lines within 2.46 resolution elements of each recovered line to that recovered line, $99 \%$ of the lines in the simulation are recovered. These completeness values for $3 \sigma$ lines are $49 \%$ and $98 \%$ respectively. Obviously, FINDSL can do nothing to help us overcome the finite resolution of the data, but when this is taken into consideration, this test indicates that it does a good job of recovering the lines it is capable of recovering.

Our simulations also revealed another interesting point. Of the $3 \sigma$ lines "recovered" by FINDSL, a small percentage, $\sim 0.25 \%$, were not generated by the simulation program. In other words, FINDSL found some lines in the noise. This was not true of the $5 \sigma$ lines, however, so we expect no spurious lines to be present in the line lists used for the analysis of Lyman $\alpha$ forest statistics. We do use lines with significance levels between $3 \sigma$ and $5 \sigma$ for metal line identification purposes; but expect that any low occurrence of spurious lines would have no effect on those identifications due to the all the constraints that were placed upon metal line matches to qualify as true metal line systems, which are discussed in more detail below.

The July 1993 CCD data suffers from a gradient in the FWHM across the spectrum as discussed in Section 2.1, rising from $\sim 1.1 \AA$ in the blue end to $\sim 2.5 \dot{A}$ in the red (Figure 2.1). This variation has some impact on how FINDSL identifies significant lines. Using a FWHM of $2.5 \AA$ for $\lambda>3700 \AA$, results in fewer significant lines identified relative to the case where a FWHM of $1.1 \AA$ is used over the full spectrum.

Inspection of the fits for these two cases for several objects in our sample leads us to conclude that the two cases give consistent total equivalent widths for absorption features, but that using a search window based on a FWHM of $1.1 \AA$, even at the red ends of these spectra, gives the most reasonable line identifications, as the larger window tended to blend distinct features together. Table 2 gives a list of the vacuum, heliocentric wavelengths of all lines identified along with the equivalent width of each line as determined by a Gaussian fit to the line.

We generated additional synthetic $\mathrm{Ly}-\alpha$ forest spectra with no metal lines in order to determine the maximum number of metal line identifications that our software will identify spuriously in the Ly- $\alpha$ forest, or equivalently, the minimum number of metal line identifications needed to qualify as a metal line system, cf. Dobrzycki and Bechtold (1996). The simulation parameters used in this case were $\gamma=1.5, \beta=1.46$, $\left.\mathrm{N}_{\text {lower }}=2 \times 10^{12} \mathrm{~cm}^{-2}, \mathrm{~N}_{\text {upper }}=10^{16} \mathrm{~cm}^{-2},<\mathrm{b}\right\rangle=28 \mathrm{~km} \mathrm{~s}^{-1}$, and $\sigma_{b}=10 \mathrm{~km} \mathrm{~s}^{-1}$. We find that our program will find metal line systems in the Lyman $\alpha$ forest that may appear to be reasonable based on the species present and doublet ratios, if the number of required matches between the data and a table of possible metal lines is set to a number less than four if there are less than $\sim 100$ lines in the spectrum, and less than five if there are more than $\sim 100$ identified lines in the spectrum. If a system shows lines redward of Ly- $\alpha$ emission, this requirement is relaxed since this spectral region is free of $\mathrm{Ly}-\alpha$ forest absorption lines.

The search list of metal lines, their wavelengths, and their $f$ values was taken from Table 4 of Morton et al. (1988) supplemented with Fe II $\lambda 1143$ and $\lambda 1145$ and N I $\lambda 1135$ from their Table 3. Redshift systems were identified by first running our metal line searching program to find systems with our prescribed number of matches. Metal line matches within $3 \sigma$ of an observed significant line are counted. The output of this program was analyzed for consistency with required doublet ratios and $\mathbf{f}$ values. Lines found by this program were rejected if a) the weaker line of a doublet is detected while the stronger is not or $b$ ) a weak line of a species is detected while a stronger line of the
same species and ionization state is not (eg. Si II $\lambda 1304$ is detected but Si II $\lambda 1260$ is not). Next, lines with rest equivalent width greater than about $1 \AA$ were tentatively identified as Ly- $\alpha$ for a metal line system. The resulting redshift was used as a trial redshift and the matches with metal lines were noted and critiqued as above.

A metal line system identification is considered a strong one if it is corroborated by a spectrum from the literature that extends redward of Ly- $\alpha$ emission. A system is considered reasonable if it consists of at least the minimum number of lines and the strengths of those lines are in agreement with the expected $f$ values and range in doublet ratios.

An identification is marked as a possible identification if either the doublet ratio gives a value less than one or greater than two, ie. one of the doublet lines is a blend if it is present, or if the separation between that line and another line in the redshift system (excluding doublet pairs) is greater than $\sim 200 \mathrm{~km} \mathrm{~s}^{-1}$ but less than $\sim 300 \mathrm{~km}$ $\mathbf{s}^{-1}$. Once metal lines were identified, they were removed from the line list used for the Ly- $\alpha$ forest analysis. Also, the redshift path covered by each line was removed from the analysis by removing a region of width $2.5 \sigma$ centered on the wavelength centroid of the line. The line $\sigma$ and line centroid were taken from the Gaussian fit.

The redshift of any spurious line in our $3 \sigma$ line lists identified as a metal line would also have to match with other metal lines in our line list, specifically to a strong Lyman $\alpha$ line if it is observable in the spectrum. For this reason, we expect that the possible low occurrence of false lines of less than $5 \sigma$ significance in our line lists has no effect on the metal line systems identified below.

### 2.3 Results and Discussion

The number of Ly- $\alpha$ lines per unit redshift per unit equivalent width can be parametrized as follows:

$$
\begin{equation*}
\frac{\partial^{2} \mathcal{N}}{\partial z \partial W}=\frac{A_{0}}{W^{*}}(1+z)^{\gamma} \exp \left(-\frac{W}{W_{*}}\right) \tag{2.1}
\end{equation*}
$$

Integrating this equation over equivalent width with a constant threshold equivalent width throughout each spectrum gives

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=\mathcal{A}_{0}(1+z)^{\gamma} \tag{2.2}
\end{equation*}
$$

To solve for the parameters $\gamma$ and $W^{*}$, we use a maximum likelihood technique which allows for an equivalent width threshold that varies with wavelength. We also derive these parameters using various fixed threshold values; and in this case, the procedure reduces to the method described in the Appendix of MHPB, using corrected expressions for their equations (A8) and (A2a). However, the variable threshold information is still used in the fixed threshold case, as regions of the spectrum for which the threshold lies above the fixed value, ie. where no significant lines could be detected even if they were present, are excluded.

The solutions for the statistics $\gamma$ and $W^{*}$ are listed in Table 2.3. Each sample excludes regions of the spectra within $\Delta z$ of 0.15 of the QSO emission redshift, chosen to eliminate any effects on the line density due to proximity to the QSO. A variable equivalent width threshold gives a value of $1.23 \pm 0.16$ for $\gamma$. This is lower than the value of $2.75 \pm 0.29$ found by LWT for for a fixed equivalent width threshold of $0.36 \AA$ over the range $1.7<z<3.8$, and the value of $1.89 \pm 0.28$ found by B94 for a fixed threshold of $0.32 \AA$ over the range $1.6<z<4.1$. Using a fixed threshold of $0.32 \AA$, the value of $\gamma$ derived from our data is $1.88 \pm 0.22$, in good agreement with that of B94. In Table 2.3, no error is quoted for $\mathcal{A}_{0}$ because it is strongly correlated with the error in $\gamma$.

We calculate the Kolmogorov-Smirnov (KS) probability that a power law number density distribution given by Equ. 2.2 for each of these values of $\gamma$ is a good representation of the data (cf. Appendix of MHPB). A high probability $\left(\mathrm{P}_{K S}\right)$ that the maximum deviation from the cumulative number distribution could occur by chance if the data set is drawn from an assumed parent distribution indicates that the choice of parent distribution is justified. These results are included in Table 2.3. The total
sample and each of the subsamples is described well by a single power law, as illustrated by the high KS probabilities obtained. The KS probability obtained from our data set with a fixed equivalent width threshold of $0.32 \AA$ and the LWT $\gamma$ value of 2.75 is 0.0020 , while the B94 value of 1.85 gives 0.97 , as it is in good agreement with our maximum likelihood result.

The errors in $\gamma$ and $W^{*}$ are calculated by our software by fitting a parabola to the peak of the logarithm of the likelihood function, using the fact that the likelihood function itself should be distributed as a Gaussian in $\gamma$ and $W^{*}$ near its maximum value. In order to avoid any assumptions about the distribution of the statistics of interest, a resampling technique was used to independently estimate the distribution. Jackknife samples (Babu \& Feigelson 1996, Efron 1982) of our original data set were constructed, 100 in all, each with one QSO from the original sample removed. We used the same program to calculate $\gamma$ and $W^{*}$ for each jackknife sample, for the case of $W_{t h r}=0.32 \AA$. The goal is to understand how the values of these statistics found by our software vary with random variations in the data. The weighted mean of all the jackknife values for $\gamma$ is 1.91 and for $W^{*}$ it is $0.309 \AA$. Since we cannot treat each of the 100 values of these statistics as independent measurements of $\gamma$ and $W^{*}$, the jackknife errors show how well the error calculated by the software estimates the true distribution of the statistics calculated. The jackknife results for $\sigma_{\gamma}$ and $\sigma_{W}$ - are 0.26 and 0.011 respectively. The fact that the jackknife errors are $\sim 20 \%$ larger than the error calculated by our software may reflect the fact that the jackknife estimate of the variance tends to be conservative (Efron 1982) or it may indicate the the presence of additional sources of random error. In any case, the jackknife results do agree with the total data set result to well within the errors.

The two questions we now ask are whether the number densities of strong and weak lines evolve differently with redshift and whether there is a difference in $\gamma$ for low and high redshift subsamples, ie. does $\gamma$ evolve over the history of the universe after the observed break at $z \sim 1.7$ ? In this context, strong lines will refer to lines
with rest equivalent widths greater than $0.32 \AA$ and weak lines will refer to those with rest equivalent widths between $0.16 \AA$ and $0.32 \AA$. The total absorption line sample was divided into low and high redshift subsamples at an absorption redshift of 2.5, giving 1084 and 995 lines in each subset, respectively. For the remainder of this paper, the low and high redshift subsamples will refer to Lyman $\alpha$ forest absorption lines with redshifts above and below 2.5, respectively.

Figure 2.4 is a set of plots of $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ for the various subsamples of our data set which are binned solely for display purposes. The straight lines are derived from the parameters given in Table 2.3. Figure 4 a shows the low and high redshift subsamples and the solutions for each along with the solution for the total sample. Each of these are generated with a fixed equivalent width threshold of $0.32 \AA$. Figure 4 b shows the results for strong ( $\mathrm{W}>0.32 \AA$ ) and weak lines $(0.16<W<0.32 \AA)$ considered separately. Column 8 of Table 2.3 lists the KS probabilities for each case considered.

No $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ plots are shown and no KS probabilities are quoted for any case in which a variable threshold was used. This is because the distribution in redshift is now related to the equivalent width of each line. The separation of these two distributions, which is possible in the case of a constant threshold, is not possible; and the formalism of MHPB can no longer be applied. Nevertheless, since the implementation of a variable threshold allows the most efficient use of the data, we consider these values of $\gamma$ to be reliable, especially in light of the reasonable KS probabilities in the constant threshold cases.

Considering the moderate resolution and signal-to-noise of our data, it is worth investigating how well we are recovering the true parameters describing the line distribution. Recall from the discussion of the simulations in Section 2.2 that our $5 \sigma$ line lists are $55 \%$ complete due to blending. To address this point, we generated more sets of artificial spectra based on the 56 objects in our data set for which we have detailed spectral information in the way described in Section 2.2. The redshift of each

QSO in these sets is equal to that of one of the 39 new MMT spectra presented in this paper or to that of one of the 17 spectra presented in Dobrzycki and Bechtold (1996). In order to investigate how signal-to-noise impacts this analysis, we created three sets of these 56 artificial spectra with the resolution of the data, $\sim 1 \AA$, one set having signal-to-noise ratios half that of the data (median $S / N \sim 5$ ), another having signal-to-noise ratios equal to that of the data (median $\mathrm{S} / \mathrm{N} \sim 10$ ), and another having twice the signal-to-noise of the data (median $\mathrm{S} / \mathrm{N} \sim 20$ ). The input parameters used were $\gamma=1.88, \beta=1.46, N_{\text {lower }}=10^{13} \mathrm{~cm}^{-2}, N_{\text {upper }}=10^{16} \mathrm{~cm}^{-2},\langle\mathrm{~b}\rangle=28 \mathrm{~km}$ $\mathrm{s}^{-1}$, and $\sigma_{b}=10 \mathrm{~km} \mathrm{~s}^{-1}$.

In the low S/N simulation, FINDSL spuriously identified one simulated line, out of 1722 lines above threshold, as two separate lines, both of $5 \sigma$ significance or greater. This did not occur in either the data $\mathrm{S} / \mathrm{N}$ simulation, or in the high $\mathrm{S} / \mathrm{N}$ simulation, so we remain confident that the Lyman $\alpha$ lines in our line lists are real absorption features.

We also generated set of synthetic spectra with higher resolution than the data. Two sets were made with resolution $\Delta \lambda \sim 0.7 \AA$, one with the same signal-to-noise as the data, and another with median S/N $\sim 20$. Finally, a Keck/HIRES data set was simulated by generating spectra with $\Delta \lambda \sim 0.2 A$ and median $S / N \sim 40$.

The simulation line lists were analyzed in the same way as the data to determine the value of $\gamma$ input into the FINDSL analysis. This $\gamma$ is not necessarily equal to the simulation input $\gamma, 1.88$, because, in generating the artificial spectra, the simulation software does not fix the redshift and equivalent width distributions by the input parameters, but rather draws line redshifts and equivalent widths from a distribution given by Equation 2.2. FINDSL line lists were then generated and $\gamma$ was calculated again using these line lists. This was done for both the variable threshold and the case of an equivalent width threshold of $0.32 \AA$ for all redshifts, and at high and low redshifts separately. The two values of $\gamma$ for each case are compared with each other in order to determine how well the redshift distribution in the FINDSL line
lists reflects the distribution output by the simulations. The results are listed in Table 2.4. The simulation resolution and median signal-to-noise ratio are given in the first two columns; the redshift range and the threshold used for the $\gamma$ solution are given in columns (3) and (4); and the values of $\gamma$ derived from the simulation line lists ( $\gamma_{\text {simulation }}$ ) and from the FINDSL line lists ( $\gamma_{\text {FINDSL }}$ ) are given in columns (5) and (6), respectively. DB96 discuss this simulation software in detail and use it to investigate the column density distribution of Lyman $\alpha$ lines. Their data set, a subset of ours, encompassed a limited redshift path and was therefore insensitive to a determination of $\gamma$ from the simulations. Presumably, if we ran the large number of simulations for which this software was designed, we would recover $\gamma=1.88$ in column (5) of Table 2.4; but since we are merely trying to determine the reliability of our methods for identifying significant lines, we will leave this for future work. These Monte-Carlo simulations create line lists by distributing lines according to the input value of $\gamma$, which is independent of redshift and equivalent width. It is for this reason, and because we have created a relatively small number of synthetic spectra in order to simulate our data set, that we do not take the values of $\gamma$ derived either from the simulation line lists or from the FINDSL line lists to truly reflect the redshift distribution of Lyman $\alpha$ lines. We use these simulations only to investigate how well our techniques for identifying significant lines and calculating $\gamma$ recovers the value input into the FINDSL analysis.

Figure 2.5 also demonstrates these results. It shows the number of sigma difference between the output (FINDSL line lists) and input (simulation line lists) values of $\gamma$, (a)-(c) for the variable threshold case and (d)-(f) for the $\mathrm{W}_{t h r}=0.32 \AA$ case. The square points and solid lines indicate the results for the simulations at the resolution of the data in this paper, $\Delta \lambda \sim 1 \AA$. The open triangles and dotted lines show the results for the simulations at higher resolution, $\Delta \lambda \sim 0.7 \AA$; and the filled triangle shows the result for the Keck/HIRES simulation, $\Delta \lambda \sim 0.2 \AA$.

Histograms of the line distributions used in the input (simulation line lists) and
output (FINDSL line lists) $\gamma$ solutions are shown in Figure 2.6(a-d). Also, plots of $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ analogous to those in Figure 2.4 for the data resolution, data $\mathrm{S} / \mathrm{N}$, constant threshold simulations are shown in Figure 2.7. As in Figures 2.6(a-d), the solid lines correspond to the maximum likelihood solution for $\gamma$ and $\mathcal{A}_{0}$ for the simulation line lists and the dashed lines correspond to the solution for the FINDSL line lists. These figures demonstrate that the process of simulation lines above threshold being "blended out" with other features in the final FINDSL line lists dominates over lines below threshold being "blended in" by blending with other features below threshold in all cases. Overall, therefore, the FINDSL line lists suffer from a net loss of lines due to the blending out of significant features.

However, this blending has not significantly affected the value of $\gamma$. The only case for which the simulation and subsequent FINDSL solutions for $\gamma$ differ by more than $1.5 \sigma$, indicated by the dashed-dotted lines in Figure 2.5, is the constant threshold solution for the lowest $\mathrm{S} / \mathrm{N}$ simulation at low redshift, the leftmost point in Figure 2.5(b). It should be noted that some visual inspection of the simulation spectra was necessary to achieve this overall agreement between the simulation and the FINDSL $\gamma$ 's. This examination was commensurate with that done on the data, especially during the course of the metal line identifications, so no significant bias is introduced into the simulation analysis by doing this. The FINDSL program tended to miss some weak lines in the high redshift spectra due to crowding of features. Some lines were also missed by FINDSL at low redshift, where the signal-to-noise is lowest. The equivalent width thresholds used in the solution for $\gamma$ required that the weakest lines at low $\mathrm{S} / \mathrm{N}$ be left out of the simulation line list solution, so missing them with FINDSL had little effect. However, in some cases, FINDSL either failed to find lines above threshold at low $\mathrm{S} / \mathrm{N}$ or failed to fit them with the proper equivalent width. These omissions did adversely affect the agreement between the $\gamma$ solutions, as these lines were included in the solution using simulation line lists. Upon inspection of the simulated spectra, all of these lines were identified and the simulation and FINDSL line list solutions for
$\gamma$ were brought into agreement.
For the total sample and the high redshift subsample, including weak lines in the maximum likelihood solution tends to make $\gamma$ more shallow. Both our data and high resolution work (Cristiani et al. 1995, Giallongo et al. 1996) indicate that the tendency for $\gamma$ to change in either direction when weaker lines are included is not a significant one. Decreasing the column density cutoff from $\log \left(\mathrm{N}_{H I}\right)=13.8$ to 13.3 at $z \sim 3$, Cristiani et al. (1995) find that $\gamma$ increases from 1.86 to 2.17 ; but this is a change of less than $1 \sigma$. Giallongo et al. (1996) find that decreasing the column density cutoff from $\log \left(\mathrm{N}_{H I}\right)=14$ to 13.3, again at $z \sim 3$, decreases $\gamma$ from 2.7 to 2.49 , $\sim 1 \sigma$. However, using only weak lines for our total sample gives a $\gamma$ of $0.26 \pm 0.33$, a value consistent with no evolution for $q_{0}=0.5$; while using all lines with rest equivalent width greater than $0.32 \AA$ gives a value $4 \sigma$ larger, 1.88. In the case of the high redshift subsample, this difference is $2.6 \sigma$. Weak lines being blended out in the crowded, high redshift regions of the spectra is undoubtedly contributing to this effect. In our simulations, lines with rest equivalent widths between $0.16 \AA$ and $0.32 \AA$ yield a $\gamma$ of $2.25 \pm 0.40$ for the simulation output lines, while the FINDSL line lists give a significantly lower value of $1.30 \pm 0.49$. The plots of $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ analogous to Figure 2.7 for these weak lines are shown in Figure 2.8; and this solution for all redshifts is shown in panel (a). Recall that the input simulation redshift distribution is independent of the line width. By contrast, the simulation line list and FINDSL line list values of $\gamma$ for lines with equivalent widths greater than $0.32 \AA$ are $1.62 \pm 0.27$ and $1.70 \pm 0.30$, respectively. This indicates that though we can be confident that we are recovering the true $\gamma$ for lines with equivalent widths greater than 0.32 A . weak lines blended out at high redshift in our data may indeed produce this flattening of $\gamma$ seen when weak lines are included in the solution.

For the low redshift subsample, the weak lines give a steeper $\gamma$, but this difference is not statistically significant. The Weymann et al. (1998) results at $z<1.7$ suggest the opposite, that lines of higher rest equivalent width yield larger values of
$\gamma$. These authors find a difference in the evolution rates for $\mathrm{Ly}-\alpha$ absorbers with and without identified associated metal lines. Their interpretation of this is that it can be attributed to a difference in the rate of evolution of lines of different strengths. This scenario is supported by the higher redshift results of Kim et al. (1997). Their high resolution data suggest that there is a break in the column density distribution of Ly- $\alpha$ lines at $\log \left(N_{H I}\right) \geq 14.8$ and $z \sim 3.3$ and that this break occurs at lower column densities and becomes more pronounced as redshift decreases. These results imply that weak lines should show a flatter $\gamma$ at all redshifts and that the difference in the rate of evolution between strong and weak lines should be more significant at redshifts less than 2.5 than at redshifts greater than 2.5.

The $\gamma$ 's derived from the simulation and FINDSL line lists for the spectra generated at the data resolution and signal-to-noise listed in Table 2.4 are generally in good agreement with one another for strong and weak lines at low and high redshift, noting however, the large uncertainties for the weak line $\gamma$ 's. The FINDSL $\gamma$ 's for weak lines for all redshifts and at low redshift are systematically lower than the simulation $\gamma$ 's, due to blending out of weak features preferentially at high redshift. The high redshift solution does not suffer from this as lines are evenly blended out at all redshifts greater than 2.5, as demonstrated in Figure 2.8(a-c). In any case, this comparison indicates that there is no tendency for blending to work to artificially produce the trend noted above, namely that the $\gamma$ for weak lines is steeper than the $\gamma$ for strong lines at low redshift, contrary to the results of other authors.

For a variable threshold at high redshifts, $\gamma$ flattens by $1.5 \sigma$ compared to the value found for low redshift lines, to $0.64 \pm 0.47$ for $z>2.5$ from $1.57 \pm 0.42$ at $z<2.5$. Again, the difference is not statistically significant; but a trend exists in that the maximum likelihood values of $\gamma$ found for the low redshift subsample are larger than those found for the high redshift subsample in all cases in which weak lines are included, while for strong lines, $\gamma$ increases from low to high redshift. The agreement between the $\gamma$ 's derived from the simulation line lists and the FINDSL line
lists indicates that, at the resolution and signal-to-noise of the data, this trend is not artificially imposed by blending.

Equivalently, one can investigate the distribution in equivalent width as a function of redshift. The value of the parameter $W^{*}$ increases from low to high redshift from $0.282 \AA$ to $0.330 \AA$ in the case of a constant $0.32 \AA$ threshold, a difference of $\sim 3 \sigma$ in the sense that the distribution is more shallow at high redshift. Both of these results imply that there exist more weak lines relative to strong ones at low redshift than at high redshift. Given the discussion above, it is likely that at least some of this difference can be attributed to increased blending of weak lines at high redshifts. Nevertheless, the Kim et al. (1997) analysis supports this interpretation, as do the results of the hydrodynamic simulations of Davé et al. 1999. These authors find that $W^{*}$ does indeed increase with redshift from $z=0$ to $z=3$ due to the onset of structure formation. The values of $W^{*}$ they derive from their simulated spectra at high resolution are smaller than those measured in this paper or at low redshift by Weymann et al. (1998). They find, however, that the effects of blending in even low redshift, moderate resolution spectra, comparable to the FOS data, can raise the measured values to those found by Weymann et al. (1998).

This effect is demonstrated by Figure 2.9, a histogram of the rest equivalent width distribution of lines in the simulation and FINDSL line lists for the data resolution ( $\sim 1 \AA$ ) simulations with median signal-to-noise ratios of 5,10 , and 20 in the variable threshold case. As expected, the number of lines blended out is largest at low equivalent width, flattening out the overall distribution and in turn raising the value of $W^{*}$ derived.

If a fixed equivalent width threshold of $0.32 \AA$ is used (rows $9,11,15$, and 17 in Table 2.3), weak lines are thrown out and the distribution in redshift is flatter at low redshift than at high redshift, though not significantly so: $\gamma=1.30 \pm 0.60$ for $z<2.5$, versus $1.69 \pm 0.60$ for $z>2.5$, a difference of less than $0.5 \sigma$. Interestingly, StenglerLarrea et al. (1995) find $\gamma=1.50 \pm 0.39$ for Lyman limit absorbers between $z=0.32$
and $z=4.11$, in reasonable agreement with our values of $\gamma$ using $W_{t h r}=0.32 \AA$ for both the low and high redshift subsamples. The total sample of lines with $\mathrm{W}>0.32 \AA$ gives a somewhat larger value of $\gamma, 1.88 \pm 0.22$, but including the low redshift data of Bahcall et al. (1993) yields a value of $1.70 \pm 0.19$, consistent with the result for Lyman limit systems. It has been proposed that Ly- $\alpha$ absorbers with $\log \left(N_{H I}\right) \gtrsim 14$, the value of the break in the column density distribution, are associated with the outer halos of galaxies responsible for Lyman limit systems and damped Lyman $\alpha$ systems (Giallongo et al. 1996, Lanzetta et al. 1995, 1996, Chen et al. 1998). This column density is approximately equivalent to the equivalent width threshold of $0.32 \AA$ used in this study; and the agreement between our values of $\gamma$ and that for Lyman limit systems lends some credence to this scenario.

Table 2.1: Summary of $z \approx 2$ QSO Observations

| QSO | Alternate Name | $z_{e m}$ | Ref. <br> (a) | $\mathrm{m}_{V}$ <br> (b) | Instr. <br> (c) | Date | Total Exposure (seconds) | Wavelength ( $\AA$ ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0006+020 |  | 2.34 | 1 | 17.5 | 2 | 15Nov93 | 7200 | 3200-4088 |
| 0027+018 | UM 247 | 2.31 | 2 | 18.9 | 1 | 250 Ct 92 | 3600 | 3136-4118 |
| 0037-018 | UM 264 | 2.34 | 1 | 18.0 | 2 | 7 Jan 94 | 7200 | 3205-4109 |
| 0049+007 | UM 287 | 2.27 | 3 | 17.8 | 1 | 23-25Oct92 | 9600 | 3150-4111 |
| $0123+257$ | PKS | 2.37 | 3 | 17.5 | 2 | 16Nov93 | 9000 | 3198-4094 |
| 0150-202 | UM 675 | 2.14 | 4 | 17.1 | 1 | 24-25Oct92 | 6000 | 3173-4126 |
| 0153+744 | S5 | 2.34 | 3 | 16.0 | 2 | 15Nov93 | 3600 | 3192-4088 |
| 0226-038 | PKS | 2.07 | 3 | 16.9 | 2 | 16Nov93 | 3000 | 3198-4095 |
| 0348+061 |  | 2.05 | 4 | 17.6 | 1 | $250 \mathrm{ct92}$ | 2400 | 3130-4112 |
| $0400+258$ | B2 | 2.10 | 1 | 18.0 | 2 | 7 Jan 94 | 3000 | 3209-4121 |
| 0747+613 |  | 2.49 | 1 | 17.5 | 1 | 250 ct 92 | 3600 | 3323-4269 |
| 0836+710 | S5 | 2.21 | 3 | 16.5 | 2 | 15Nov93 | 3600 | 3192-4088 |
| $0848+155$ |  | 2.01 | 4 | 17.7 | 2 | 15Nov93 | 3600 | 3192-4088 |
| 0936+368 | CSO 233 | 2.02 | 1 | 17.0 | 2 | 4Apr94 | 3600 | 3176-4058 |
| 0952+338 | CSO 239 | 2.50 | 1 | 17.0 | 2 | 7Jan94 | 5400 | 3486-4389 |
| 0955+472 | PC | 2.48 | 1 | 17.7 | 2 | 7Jan94 | 3600 | 3486-4389 |
| $0956+122$ |  | 3.30 | 1 | 17.5 | 2 | 7Jan94 | 3600 | 4394-5293 |
| 1009+299 | CSO 38 | 2.63 | 1 | 16.0 | 2 | 7 Jan 94 | 3600 | 3622-4525 |
| $1207+399$ |  | 2.45 | 3 | 17.5 | 3 | 5Apr94 | 900 | 3201-4824 |
| $1210+175$ |  | 2.56 | 1 | 17.4 | 2 | 4June94 | 3600 | 3572-4453 |
| $1231+294$ | CSO 151 | 2.01 | 1 | 16.0 | 2 | 12Mar94 | 1800 | 3172-4053 |
| 1323-107 | POX188 | 2.36 | 5 | 17.0 | 2 | 4June94 | 5400 | 3200-4087 |
| 1329+412 | PG | 1.93 | 1 | 16.3 | 2 | 3June94 | 1800 | 3202-4087 |
| $1337+285$ |  | 2.54 | 1 | 17.1 | 2 | 3June94 | 3600 | 3574-4455 |
| 1346-036 |  | 2.36 | 3 | 17.2 | 2 | $18 \mathrm{Ju193}$ | 3600 | 3275-4155 |

Table 2.1: Summary of $z \approx 2$ QSO Observations (Con-
tinued)

| QSO | Alternate Name | $z_{\text {em }}$ | Ref. <br> (a) | $\begin{aligned} & \mathrm{m}_{V} \\ & \text { (b) } \end{aligned}$ | Instr <br> (c) | Date | Total Exposure (seconds) | Wavelength ( $\AA$ ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $1358+115$ |  | 2.58 | 1 | 16.5 | 2 | 18 Jul 93 | 3600 | 3547-4424 |
| $1406+492$ | CSO 609 | 2.16 | 1 | 17.0 | 2 | 3-4June94 | 3400 | 3201-4085 |
| $1408+009$ | UM 645 | 2.26 | 3 | 18.0 | 3 | 5Apr94 | 900 | 3200-4807 |
| $1421+330$ | MKN 679 | 1.90 | 4 | 16.7 | 2 | 4June94 | 1800 | 3200-4084 |
| $1422+231$ |  | 3.62 | 3 | 16.5 | 2 | 16-17Ju193 | 1800 | 4853-5716 |
| $1435+638$ |  | 2.06 | 3 | 15.0 | 2 | 16-17Jul93 | 7200 | 3100-3942 |
| $1603+383$ | HS | 2.51 | 6 | 16.9 | 4 | 12-13Apr97 | 3300 | 3532-5045 |
| $1604+290$ | KP 63 | 1.96 | 1 | 17.0 | 2 | 18 Jul 93 | 3600 | 3100-3943 |
| $1715+535$ | PG | 1.93 | 4 | 16.3 | 2 | 16-17Jul93 | 9000 | 3100-3938 |
| $2134+004$ | PKS | 1.94 | 1 | 17.5 | 1 | 24-25Oct92 | 7200 | 3173-4125 |
| $2251+244$ | PKS | 2.35 | 3 | 17.8 | 2 | 16Nov93 | 12000 | 3200-4093 |
| 2254+022 | PKS | 2.09 | 4 | 17.0 | 2 | 16-17Jul93 | 7200 | 3100-3936 |
| $2310+385$ | UT | 2.18 | 3 | 17.5 | 1 | 250ct92 | 1200 | 3200-4118 |
| $2320+079$ | PKS | 2.08 | 1 | 17.5 | 2 | 17 Jul 93 | 5400 | 3160-3940 |
| 2329-020 | UM 164 | 1.89 | 1 | 17.0 | 2 | 18 Jul 93 | 3600 | 3060-3943 |

${ }^{a}$ (1) this paper, from Ly $\alpha$ emission; (2) Baker et al. 1994; (3) Scott et al. 2000, and refs. therein; (4) Steidel \& Sargent 1991; (5) Hewitt \& Burbidge 1993; (6) Dobrzycki, Engels, \& Hagen 1999
${ }^{b}$ as listed in Hewitt \& Burbidge 1993, with the exception of $1603+383$, for which $V$ was calculated from the flux-calibrated spectrum (unpublished)
${ }^{c}$ Instrument Set-up:
(1) Big Blue Reticon, $8321 \mathrm{~mm}^{-1} 2^{\text {nd }}$ order, $1^{\prime \prime} \times 3^{\prime \prime}$ slit;
(2) $3 \mathrm{Kx} 1 \mathrm{~K} \mathrm{CCD}, 832 \mathrm{I} \mathrm{mm}{ }^{-1} 2^{\text {nd }}$ order, $1^{\prime \prime} \times 180^{\prime \prime}$ slit;
(3) $3 \mathrm{~K} \times 1 \mathrm{~K} C C D, 800 \mathrm{lmm}^{-1} 1^{\text {st }}$ order, $1^{\prime \prime} \times 180^{\prime \prime}$ slit;
(4) $3 \mathrm{KxlK} C C D, 1200 \mathrm{lmm}^{-1} 1^{\text {st }}$ order, $1^{11} \times 3^{\prime \prime}$ slit

Table 2.2: QSO Spectra from the Literature

| QSO | $z_{e m}$ | Reference |
| :--- | :--- | :---: |
| $0000-263$ | 4.111 | 1 |
| $0001+087$ | 3.243 | 1 |
| $0002+051$ | 1.899 | 2 |
| $0002-422$ | 2.763 | 3,4 |
| $0014+813$ | 3.384 | 1,5 |
| $0029+073$ | 3.294 | 1 |
| $0058+019$ | 1.959 | 6 |
| $0100+130$ | 2.690 | 4 |
| $0114-089$ | 3.205 | 1,5 |
| $0119-046$ | 1.937 | 7 |
| $0142-100$ | 2.727 | 6 |
| $0237-233$ | 2.222 | 6 |
| $0256-000$ | 3.374 | 1,5 |
| $0301-005$ | 3.223 | 1 |
| $0302-003$ | 3.286 | 1,5 |
| $0334-204$ | 3.126 | 1 |
| $0421+019$ | 2.051 | 2 |
| $0424-131$ | 2.166 | 6 |
| $0453-423$ | 2.656 | 3,4 |
| $0636+680$ | 3.174 | 1,5 |
| $0731+653$ | 3.033 | 1 |
| $0831+128$ | 2.739 | 1,5 |
| $0837+109$ | 3.326 | 6 |
| $0848+163$ | 1.925 | 6 |
| $0905+151$ | 3.173 | 1 |
| $0913+072$ | 2.784 | 1,5 |
| $0938+119$ | 3.192 | 1 |
| $1017+280$ | 1.928 | 6 |
| $1033+137$ | 3.092 | 1 |
| $1115+080$ | 1.725 | 2 |
| $1159+124$ | 3.502 | 6 |
| $1206+119$ | 3.108 | 1,5 |
| $1208+101$ | 3.822 | 1 |
| $1215+333$ | 2.606 | 1,5 |
| $1225-017$ | 2.831 | 1,5 |
| $1225+317$ | 2.200 | 4 |
| $1247+267$ | 2.039 | 6 |
| $1315+472$ | 2.590 | 1,5 |
|  |  |  |

Table 2.2: Summary of $z \approx 2$ QSO Observations (Continued)

| QSO | $z_{e m}$ | Reference |
| :---: | :---: | :---: |
| $1334-005$ | 2.842 | 1,5 |
| $1400+114$ | 3.177 | 1 |
| $1402+044$ | 3.206 | 1 |
| $1410+096$ | 3.313 | 1 |
| $1442+101$ | 3.554 | 1 |
| $1451+123$ | 3.251 | 1 |
| $1511+091$ | 2.878 | 6 |
| $1512+132$ | 3.120 | 1 |
| $1548+092$ | 2.748 | 1,5 |
| $1601+182$ | 3.227 | 1 |
| $1602+178$ | 2.989 | 1 |
| $1607+183$ | 3.134 | 1,5 |
| $1614+051$ | 3.216 | 1 |
| $1623+269$ | 2.526 | 1,5 |
| $1700+642$ | 2.744 | 1,5 |
| $1738+350$ | 3.239 | 1 |
| $1946+770$ | 3.020 | 5 |
| $2126-158$ | 3.280 | 4 |
| $2233+131$ | 3.295 | 1 |
| $2233+136$ | 3.209 | 1 |
| $2311-036$ | 3.041 | 1 |

References:
(1) Bechtold 1994;
(2) Young, Sargent, \& Boksenberg 1982a;
(3) Sargent et al. 1979;
(4) Sargent et al. 1980;
(5) Dobrzycki \& Bechtold 1996;
(6) Sargent, Boksenberg, \& Steidel 1988;
(7) Sargent, Young, \& Boksenberg 1982

Table 2.3. Maximum Likelihood Estimations of $\gamma, W^{*}$, and $\mathcal{A}_{\mathbf{0}}$

| Sample <br> (a) | No. lines | W limit | $\gamma$ <br> $(\mathrm{b})$ | $\mathrm{W}^{*}(\AA)$ <br> $(\mathrm{b})$ | $\mathcal{A}_{0}$ <br> $(\mathrm{~b})$ | $\mathrm{P}_{\boldsymbol{K S}}$ |
| :---: | :---: | :--- | :--- | :---: | :---: | :---: |
| 1 | 2079 | variable | $1.23 \pm 0.16$ | $0.313 \pm 0.006$ | - | - |
| 1 | 1295 | $\mathrm{~W}>0.16 \AA$ | $1.35 \pm 0.21$ | $0.300 \pm 0.008$ | 20.1 | 0.46 |
| 1 | 1131 | $\mathrm{~W}>0.32 \AA$ | $1.88 \pm 0.22$ | $0.307 \pm 0.009$ | 5.78 | 0.98 |
| 1 | 1208 | $0.16<\mathrm{W}<1.00 \AA$ | $1.11 \pm 0.22$ | $0.238 \pm 0.006$ | 25.4 | 0.53 |
| 1 | 1007 | $0.32<\mathrm{W}<1.00 \AA$ | $1.59 \pm 0.24$ | $0.226 \pm 0.007$ | 7.47 | 0.96 |
| 1 | 555 | $0.16<\mathrm{W}<0.32 \AA$ | $0.26 \pm 0.33$ | $0.075 \pm 0.003$ | 34.1 | 0.26 |
| 2 | 1084 | variable | $1.57 \pm 0.42$ | $0.284 \pm 0.008$ | - | - |
| 2 | 605 | $\mathrm{~W}>0.16 \AA$ | $2.42 \pm 0.62$ | $0.257 \pm 0.010$ | 5.86 | 0.72 |
| 2 | 534 | $\mathrm{~W}>0.32 \AA$ | $1.30 \pm 0.60$ | $0.282 \pm 0.012$ | 11.1 | 0.93 |
| 2 | 578 | $0.16<\mathrm{W}<1.00 \AA$ | $2.26 \pm 0.63$ | $0.218 \pm 0.009$ | 6.77 | 0.53 |
| 2 | 491 | $0.32<\mathrm{W}<1.00 \AA$ | $1.07 \pm 0.63$ | $0.229 \pm 0.010$ | 13.2 | 0.78 |
| 2 | 298 | $0.16<\mathrm{W}<0.32 \AA$ | $2.47 \pm 0.88$ | $0.073 \pm 0.004$ | 2.72 | 0.93 |
| 3 | 995 | variable | $0.64 \pm 0.47$ | $0.348 \pm 0.010$ | - | - |
| 3 | 690 | $\mathrm{~W}>0.16 \AA$ | $0.46 \pm 0.55$ | $0.338 \pm 0.012$ | 67.9 | 0.87 |
| 3 | 597 | $\mathrm{~W}>0.32 \AA$ | $1.69 \pm 0.60$ | $0.330 \pm 0.013$ | 7.62 | 0.83 |
| 3 | 630 | $0.16<\mathrm{W}<1.00 \AA$ | $-0.05 \pm 0.58$ | $0.256 \pm 0.010$ | 125. | 0.98 |
| 3 | 516 | $0.32<\mathrm{W}<1.00 \AA$ | $1.26 \pm 0.65$ | $0.223 \pm 0.009$ | 11.8 | 0.92 |
| 3 | 257 | $0.16<\mathrm{W}<0.32 \AA$ | $-1.22 \pm 0.94$ | $0.077 \pm 0.004$ | 251. | 0.86 |

(a) 1- entire sample; 2- low redshift subsample; 3 - high redshift subsample
(b) see Equ. 2.2

Table 2.4: Simulation Results for $\gamma$

| $\begin{gathered} \hline \Delta \lambda(\AA) \\ (1) \\ \hline \end{gathered}$ | $\begin{gathered} \hline \text { median } \mathrm{S} / \mathrm{N} \\ (2) \\ \hline \end{gathered}$ | $z$ range <br> (3) | W limit (4) | $\gamma_{\text {simulation }}$ <br> (5) | $\gamma_{\text {FINDSL }}$ <br> (6) |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1.0 | 4.9 | all $z$ | variable | $1.99 \pm 0.25$ | $1.71 \pm 0.30$ |
| 1.0 | 4.9 | $z<2.5$ | variable | $1.47 \pm 0.74$ | $2.82 \pm 0.84$ |
| 1.0 | 4.9 | $z>2.5$ | variable | $2.25 \pm 0.76$ | $1.88 \pm 0.98$ |
| 1.0 | 4.9 | all $z$ | $0.32 \AA$ | $2.33 \pm 0.37$ | $1.86 \pm 0.42$ |
| 1.0 | 4.9 | $z<2.5$ | $0.32 \AA$ | $2.24 \pm 1.19$ | $2.42 \pm 1.32$ |
| 1.0 | 4.9 | $z>2.5$ | $0.32 \AA$ | $3.12 \pm 1.12$ | $1.38 \pm 1.28$ |
| 1.0 | 9.8 | all $z$ | variable | $1.63 \pm 0.18$ | $1.47 \pm 0.22$ |
| 1.0 | 9.8 | $z<2.5$ | variable | $2.61 \pm 0.47$ | $2.36 \pm 0.54$ |
| 1.0 | 9.8 | $z>2.5$ | variable | $0.36 \pm 0.61$ | $1.35 \pm 0.79$ |
| 1.0 | 9.8 | all $z$ | $0.32 \AA$ | $1.62 \pm 0.27$ | $1.70 \pm 0.30$ |
| 1.0 | 9.8 | $z<2.5$ | $0.32 \AA$ | $1.85 \pm 0.68$ | $2.90 \pm 0.76$ |
| 1.0 | 9.8 | $z>2.5$ | $0.32 \AA$ | $1.10 \pm 0.97$ | $1.40 \pm 1.08$ |
| 1.0 | 9.8 | all $z$ | $0.16<W<0.32 \AA$ | $2.25 \pm 0.40$ | $1.30 \pm 0.49$ |
| 1.0 | 9.8 | $z<2.5$ | $0.16<\mathrm{W}<0.32 \AA$ | $5.18 \pm 1.26$ | $3.88 \pm 1.50$ |
| 1.0 | 9.8 | $z>2.5$ | $0.16<\mathrm{W}<0.32 \AA$ | $2.51 \pm 1.23$ | $2.52 \pm 1.68$ |
| 1.0 | 19.6 | all $z$ | variable | $1.91 \pm 0.14$ | $1.67 \pm 0.17$ |
| 1.0 | 19.6 | $z<2.5$ | variable | $1.82 \pm 0.34$ | $1.33 \pm 0.40$ |
| 1.0 | 19.6 | $z>2.5$ | variable | $3.34 \pm 0.53$ | $2.87 \pm 0.66$ |
| 1.0 | 19.6 | all $z$ | 0.32 A | $1.79 \pm 0.24$ | $2.14 \pm 0.25$ |
| 1.0 | 19.6 | $z<2.5$ | 0.32 A | $1.48 \pm 0.57$ | $1.86 \pm 0.61$ |
| 1.0 | 19.6 | $z>2.5$ | $0.32 \AA$ | $3.61 \pm 1.00$ | $3.92 \pm 1.02$ |
| 0.7 | 9.8 | all $z$ | variable | $1.77 \pm 0.15$ | $1.56 \pm 0.18$ |
| 0.7 | 9.8 | $z<2.5$ | variable | $1.86 \pm 0.39$ | $1.46 \pm 0.46$ |
| 0.7 | 9.8 | $z>2.5$ | variable | $2.34 \pm 0.54$ | $1.73 \pm 0.67$ |
| 0.7 | 9.8 | all $z$ | 0.32 A | $2.11 \pm 0.24$ | $2.44 \pm 0.27$ |
| 0.7 | 9.8 | $z<2.5$ | 0.32 A | $2.04 \pm 0.61$ | $1.58 \pm 0.69$ |
| 0.7 | 9.8 | $z>2.5$ | $0.32 \AA$ | $2.38 \pm 0.92$ | $3.12 \pm 1.01$ |
| 0.7 | 19.6 | all $z$ | variable | $1.76 \pm 0.12$ | $1.56 \pm 0.15$ |
| 0.7 | 19.6 | $z<2.5$ | variable | $1.98 \pm 0.30$ | $2.02 \pm 0.35$ |
| 0.7 | 19.6 | $z>2.5$ | variable | $2.42 \pm 0.49$ | $1.68 \pm 0.61$ |
| 0.7 | 19.6 | all $z$ | $0.32 \AA$ | $1.90 \pm 0.22$ | $2.19 \pm 0.24$ |
| 0.7 | 19.6 | $z<2.5$ | $0.32 \AA$ | $1.69 \pm 0.52$ | $1.90 \pm 0.57$ |
| 0.7 | 19.6 | $z>2.5$ | $0.32 \AA$ | $3.56 \pm 0.96$ | $4.01 \pm 1.03$ |
| 0.2 | 39.2 | all $z$ | variable | $1.41 \pm 0.10$ | $1.31 \pm 0.12$ |
| 0.2 | 39.2 | $z<2.5$ | variable | $1.22 \pm 0.23$ | $1.54 \pm 0.25$ |
| 0.2 | 39.2 | $z>2.5$ | variable | $0.72 \pm 0.48$ | $0.77 \pm 0.55$ |

Table 2.4: Simulation Results for $\gamma$ (Continued)

| $\Delta \lambda(\AA)$ | median S/N | $z$ range | W limit | $\gamma_{\text {simulation }}$ | $\gamma_{\text {FINDSL }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $(1)$ | $(2)$ | $(3)$ | $(4)$ | $(5)$ | $(6)$ |
| 0.2 | 39.2 | all $z$ | $0.32 \AA$ | $1.68 \pm 0.21$ | $1.91 \pm 0.21$ |
| 0.2 | 39.2 | $z<2.5$ | $0.32 \AA$ | $1.69 \pm 0.45$ | $2.24 \pm 0.48$ |
| 0.2 | 39.2 | $z>2.5$ | $0.32 \AA$ | $0.86 \pm 0.96$ | $-0.33 \pm 0.98$ |



Figure 2.1. FWHM of comparison lines versus wavelength for four separate instrumental setups listed in Table 2.1: solid line- (1) Big Blue Reticon, $8321 \mathrm{~mm}^{-1} 2^{\text {nd }}$ order, $1^{\prime \prime} \times 3^{\prime \prime}$ slit; short dashed line- (2) $3 \mathrm{Kx} 1 \mathrm{~K} C C D, 832 \mathrm{Imm}{ }^{-1} 2^{\text {nd }}$ order, $1^{\prime \prime} \times 180^{\prime \prime}$ slit; dotted line- Same as previous setup but with improved field flattener (see text); long dashed line- (3) $3 \mathrm{Kx} 1 \mathrm{~K} C C D, 800 \mathrm{lmm}^{-1} 1^{\text {st }}$ order, $\mathrm{l}^{\prime \prime} \mathrm{x} 180^{\prime \prime}$ slit


Figure 2.2. Spectra of 39 QSOs obtained at the MMT; solid line indicates the non flux-calibrated flux per unit frequency; dashed line indicates the continuum fit; dotted line indicates the $1 \sigma$ errors; tick marks above the continuum indicate all lines of $\geq 3 \sigma$ significance. The bottom panel shows the $5 \sigma$ equivalent width threshold as a function of wavelength.


Figure 2.3. (a) Histogram of 99 QSO redshifts, includes QSOs presented in this paper (shaded region) and objects from the literature; (b) Histogram of 3356 absorption line redshifts from QSOs presented in this paper (shaded region) and objects from the literature, using a variable equivalent width threshold, includes all lines between each QSO's Ly $\beta$ and Ly $\alpha$ emission lines


Figure 2.4. (a) $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ for $z<2.5$ (dotted line), $z>2.5$ (dashed line), and all lines (solid line) each using a fixed threshold of $0.32 \AA$; (b) $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ for different equivalent width thresholds: $W>0.16 \AA$ (dotted line); $\mathrm{W}>0.32 \AA$ (solid line) $; 0.16 \AA<\mathrm{W}<0.32 \AA$ (dashed line)


Figure 2.5. $\left(\gamma_{\text {FindsL }}-\gamma_{\text {simulation }}\right) / \sigma_{\gamma}$ versus median signal-to-noise, open squares and solid line- data resolution, $\sim 1 \AA$; open triangles and dotted line- $\Delta \lambda \sim 0.7 \AA$; filled triangles- $\Delta \lambda \sim 0.2 \AA$ : (a) variable threshold; (b) variable threshold, $z<2.5$; (c) variable threshold, $z>2.5$; (d) $W>0.32 A$; (e) $W>0.32 A, z<2.5$; (f) $W>$ $0.32 \AA, z>2.5$


Figure 2.6. Histograms of the line distribution used to solve for the simulation input $\gamma$ (solid line) and FINDSL output $\gamma$ (dashed line); vertical line at $z=2.5$ marks the division between low z and high z solutions for $\gamma$ in Fig. 2.5: (a) variable threshold, $\Delta \lambda \sim 1 \AA$ - (i) median $S / N \sim 5$, (ii) median $S / N \sim 10$, (iii) median $S / N \sim 20$; (b) variable threshold, $\Delta \lambda \sim 0.7$ A- (i) median $S / N \sim 10$, (ii) median $S / N \sim 20$, (iii) $\Delta \lambda \sim 0.2 \AA$, median $\mathrm{S} / \mathrm{N} \sim 40$; (c) constant threshold, $\Delta \lambda \sim 1 A$ - (i) median $\mathrm{S} / \mathrm{N} \sim 5$, (ii) median $\mathrm{S} / \mathrm{N} \sim 10$, (iii) median $\mathrm{S} / \mathrm{N} \sim 20$; (d) constant threshold, $\Delta \lambda \sim 0.7 \mathrm{~A}$ (i) median $S / \mathrm{N} \sim 10$, (ii) median $\mathrm{S} / \mathrm{N} \sim 20$, (iii) $\Delta \lambda \sim 0.2 A$, median $\mathrm{S} / \mathrm{N} \sim 40$


Figure 2.7. $\log (d \mathcal{N} / d z)$ versus $\log (1+z)$ for the data resolution, data $\mathrm{S} / \mathrm{N}$ simulation line lists (solid line) and FINDSL line lists (dashed line), for lines with W > 0.32 A; (a) all $z$; (b) $z<2.5$; (c) $z>2.5$


Figure 2.8. Same as Figure 2.7, but for lines with $0.16 \AA<W<0.32 \AA$.


Figure 2.9. Rest equivalent width distribution of lines in the data resolution, data $\mathrm{S} / \mathrm{N}$ simulation line lists (solid line) and in the FINDSL line lists (dashed line), variable threshold case: (a) median $\mathrm{S} / \mathrm{N} \sim 5$; (b) median $\mathrm{S} / \mathrm{N} \sim 10$; (c) median $\mathrm{S} / \mathrm{N}$ $\sim 20$

## Chapter 3

## The Ultraviolet Background at $Z>1.7$

### 3.1 Data

### 3.1.1 Spectrophotometry

Spectrophotometry of 12 sample objects in the spectral region between $\mathrm{Ly}-\alpha$ and C IV emission was obtained at the Steward Observatory Bok Telescope with the Boller and Chivens Spectrograph and the $12 \mathrm{~K} \times 8 \mathrm{~K}$ CCD on the nights of September 22, 1992, November 29, 1994, and March 28, 1995. Observations were made with a 4001 $\mathrm{mm}^{-1}$ grating with $\lambda_{b}=4889 \AA$ in the first order and a $4.5^{\prime \prime}$ slit. Spectrophotometry of the object $1422+231$ was obtained at the SO B\&C using a $600 \mathrm{l} \mathrm{mm}^{-1}$ grating with $\lambda_{b}=6681 \AA$ in the first order and a $1.55^{\prime \prime}$ slit on April 22, 1996; and the object $1603+383$ was observed by A.D. as part of the Hamburg/CfA Bright Quasar Survey on July 4, 1995 with the Fred Lawrence Whipple Observatory 1.5-meter Tillinghast telescope and FAST spectrograph, using a $3001 \mathrm{~mm}^{-1}$ grating with $\lambda_{b}=4750$ in the first order and a $3^{\prime \prime}$ slit. See Table 3.1 for a summary.

All observations except those of $1422+231$ and $1603+383$ were made with the slit set at the parallactic angle. This should not seriously effect the spectrophotometry of $1603+383$ as it was observed at a small airmass. Additionally, however, the observation of $1422+231$ was made with a slit width that is somewhat small for optimal spectrophotometry. But in any case, as discussed further below, both $1422+231$ and $1603+383$ are excluded from the proximity effect analysis due to the fact that $1422+231$ is a gravitational lens and the presence of associated absorption in the spectrum of $1603+383$. Any small errors in the spectrophotometry of the 74 objects used in the proximity effect analysis should not significantly bias the results of this work.

Object spectra were bias corrected and extracted using standard IRAF packages using $\mathrm{He}-\mathrm{Ne}-\mathrm{Ar}$ and quartz calibration exposures taken at each telescope position to perform the wavelength calibration and to correct for pixel-to-pixel variations, respectively. The data were then flux calibrated using standard star exposures. The column density of Galactic neutral hydrogen along the line of sight to each object was found using the program COLDEN, made available by J. M ${ }^{c}$ Dowell; and the spectra were thus corrected for the Galactic reddening calculated from the relation $N_{H I} / E(B-V)=4.8 \times 10^{21}$ atoms $\mathrm{cm}^{-2}$ magnitude $^{-1}$ (Bohlin 1978). The spectra and the power law continuum fits are shown in Figure 3.1.

### 3.1.2 QSO Systemic Redshifts

For the present absorption line sample, the QSO narrow emission lines discussed above all lie redward of $\sim 7600 \AA$, and into the near infrared. Spectra of four objects in this sample were obtained at the MMT with the infrared spectrometer FSpec (Williams et al. 1993) on May 20, 1994 (1207+399 and 1422+231) and April 1, 1996 (1408+009, and $1435+638$ ) using a $75 \mathrm{I} \mathrm{mm}^{-1}$ grating and a $1.2^{\prime \prime}$ slit giving a resolution of $\sim 34 \AA$ in the $K$ band. A series of exposures of each object was taken. Between each exposure, the object was moved along the slit. The total integration time is listed in Table 3.2. One object, $0836+710$, was observed on March 28,1995 with the $B \& C$, the $1200 \times 800$ CCD, a $300 \mathrm{I} \mathrm{mm}^{-1}$ grating with $\lambda_{b}=6693 \AA$ in the first order, and a $4.5^{\prime \prime}$ slit. Infrared spectra of eight objects in this sample, 0000-263, 0014+813, 0636+680, 0956+122, $1159+124,1208+101,2126-158$, were obtained using FSpec, OSIRIS on the CTIO 4 m telescope, and CRSP on the KPNO 4-m telescope as part of the PhD. dissertation of O. Kuhn. A summary of these observations is given in Table 3.2 and the spectra are displayed in Figure 3.2.

### 3.2 Ly $-\alpha$ Forest Statistics for $z_{a b s} \approx z_{e m}$ : The Proximity Effect

### 3.2.1 Spectrophotometry

In order to perform the proximity effect analysis, the flux of each QSO at the Lyman limit is needed. The spectrophotometry data discussed above was used for this purpose. A power law of the form $f_{\nu} \sim \nu^{-\alpha}$ was fit to the continua of these objects. The straight line fit to $\log \left(f_{\nu}\right)$ vs. $\log (\nu)$ was done using a robust estimation technique; and emission lines found by visually inspecting the spectrum were excluded from the points used in the fit. The measured flux at $1450 \AA$ and the value of $\alpha$ derived from this fit were used to determine the flux at $912 \AA$. For the objects we did not observe, we proceed as follows. If a flux measurement at a rest $U V$ wavelength other than $912 \AA$ exists along with a published spectral index, we use these to extrapolate to the Lyman limit. If no spectral index is available, we use the value of 0.46 (Francis 1996). The object $2134+004$ has a variable continuum (Perez et al. 1989, Corbin 1992). Therefore, although we have spectrophotometry from our own observations of this object, we take the flux measurement of these authors from their averaged spectrum produced from observations made over several months. We use this with the spectral index we derive to extrapolate to $912 \AA$.

If no rest UV spectrophotometry of an object exists, we estimate $f_{\nu}$ at $5500 \AA$ (observed) from the V magnitude given in Table 1 of Paper I with an extinction correction applied. The extinction correction was calculated using the column density of neutral hydrogen from COLDEN and the Seaton (1979) re-normalization of the composite UV-optical reddening curve of Nandy et al. (1975, and references therein). A rest-frame composite QSO spectrum (Zheng et al. 1997) with an arbitrary flux scale was redshifted by the appropriate amount for each object. The flux in the V filter was calculated by convolving this spectrum with the V filter transmission as a function of wavelength. A scaling factor was calculated so that when the redshifted QSO composite spectrum was multiplied by this factor, the resulting magnitude matched
the magnitude listed in Table 1 of Paper I. The flux at $1450 \AA$ was then taken from this scaled spectrum and this flux was extrapolated to the Lyman limit using the spectral index given in Table 3.3. A zero point flux density for the V filter of $3.81 \times$ $10^{-20} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1}$ (Johnson 1966) was used.

The asterisks in Table 3.3 mark QSOs which are known lenses or which show associated absorption in their spectra. Associated absorption is defined to be any Lyman $\alpha$ absorption within $\sim 5000 \mathrm{~km} \mathrm{~s}^{-1}$ of the QSO redshift which also shows metal lines. (See Paper I for a description of the metal line systems identified in each QSO spectrum.) These objects were excluded from the proximity effect analysis on the grounds that gas associated with the QSO or QSO host galaxy is not part of the general intergalactic medium and bulk motions within this gas may skew the results. The spectrophotometric properties adopted for the 59 QSOs from the literature are listed in Table 5 of B94.

### 3.2.2 Number of Lines with $z_{a b s} \approx z_{e m}$

The first method we use to demonstrate the proximity effect is to compare the number of lines predicted if there was no effect from the equation

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=\mathcal{A}_{0}(1+z)^{\gamma} \tag{3.1}
\end{equation*}
$$

with the number of lines counted in the spectrum as a function of distance from the QSO,

$$
\begin{equation*}
\Delta \mathcal{N}=\mathcal{N}_{\text {pred }}-\mathcal{N}_{\text {obs }} . \tag{3.2}
\end{equation*}
$$

The number of lines predicted is found by integrating Equ. 3.1,

$$
\begin{equation*}
\mathcal{N}_{\text {pred }}=\frac{\mathcal{A}_{0}}{\gamma+1}\left(\left(1+z_{\max }\right)^{\gamma+1}-\left(1+z_{\min }\right)^{\gamma+1}\right) \tag{3.3}
\end{equation*}
$$

The bins in luminosity distance from the QSO are defined according to the relation,

$$
\begin{equation*}
\Delta R=1687.5 \frac{\Delta z}{\left(1+z_{e m}\right)^{5 / 2}} h^{-1} \mathrm{Mpc} \tag{3.4}
\end{equation*}
$$

We use $h=0.75$. Figure 3.3 plots the distribution in $\mathbf{z}$ and Lyman limit luminosity of the QSOs in our sample.

The dataset was divided into low luminosity and high luminosity subsamples at $\log \left[L\left(\nu_{0}\right)\right]=31.1$, such that there were equal numbers of objects in each subsample. The Lyman limit luminosity of each object was calculated according to the expression

$$
\begin{equation*}
L\left(\nu_{0}\right)=4 \pi d_{L}^{2} \frac{f\left(\nu_{0}\right)}{\left(1+z_{e m}\right)} \tag{3.5}
\end{equation*}
$$

where the luminosity distance to the quasar, $d_{L}$ is given by

$$
\begin{equation*}
d_{L}=\frac{c\left\{q_{0} z+\left(q_{0}-1\right)\left[\left(1+2 q_{0} z\right)^{1 / 2}-1\right]\right\}}{q_{0}^{2} H_{0}} \tag{3.6}
\end{equation*}
$$

for $q_{0}>0$. In this paper, we use a value of 0.5 for $q_{0}$. Figure 3.4 plots the fractional deficit of lines, $\left(\mathcal{N}_{\text {pred }}-\mathcal{N}_{\text {obs }}\right) / \mathcal{N}_{\text {pred }}$, for the total sample and the high and low luminosity subsamples.

For the total sample, a $5.5 \sigma$ deficit of lines is found in the $0-1.5 h^{-1} \mathrm{Mpc}$ bin. The low luminosity subsample shows a deficit of lower significance ( $3.6 \sigma$ ) than the high luminosity subsample (4.6o). These deficits are expected for a proximity effect caused by enhanced ionization of HI from the quasar flux; and the marginally higher significance for high luminosity objects further suggests that this picture is legitimate.

### 3.2.3 Photoionization Model

We follow the formalism outlined in BDO to calculate a value of the mean intensity of the ionizing background in the redshift range $1.7<z<3.4$. The column density of a Ly- $\alpha$ absorber in the immediate vicinity of a quasar will be modified from the value that it would have if the quasar were not present. The amount by which the column density of HI will be reduced due to ionization by UV photons from the quasar is given by

$$
\begin{equation*}
N=N_{0}(1+\omega)^{-1} \tag{3.7}
\end{equation*}
$$

where $N$ is the observed column density of the absorber, and $N_{0}$ is the column density that the absorber would have if the quasar were absent. The column density distribution of the general $\mathrm{Ly}-\alpha$ absorber population was been shown to follow a power law over several orders of magnitude in column density,

$$
\begin{equation*}
\mathcal{N} \propto N^{-\beta} \tag{3.8}
\end{equation*}
$$

which, for a fixed limiting column density, $N_{t h r}$, (corresponding to the limiting rest equivalent width) can be integrated to give the total number of lines with column densities equal to or larger than the limiting value, $\mathcal{N}\left(N \geq N_{t h r}\right)=N_{t h r}^{-(\beta-1)}$. Thus, a proximity effect-corrected redshift distribution for a fixed rest equivalent width threshold can be derived:

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=\mathcal{A}_{0}(1+z)^{\gamma}[1+\omega(z)]^{-(\beta-1)} \tag{3.9}
\end{equation*}
$$

where $\omega$ represents a flux-scaled distance of each cloud from the QSO

$$
\begin{equation*}
\omega=\frac{F^{Q}\left(\nu_{0}\right)}{4 \pi J\left(\nu_{0}\right)} . \tag{3.10}
\end{equation*}
$$

$F^{Q}\left(\nu_{0}\right)$ is the Lyman limit flux density due to the QSO at the position of a given absorber,

$$
\begin{equation*}
F^{Q}\left(\nu_{0}\right)=\frac{L\left(\nu_{0}\right)}{4 \pi r_{L}^{2}} \tag{3.11}
\end{equation*}
$$

where $r_{L}$ is now the luminosity distance between the QSO and the absorber. We remove the dominant dependence of the line density on redshift by introducing a coevolving coordinate, $X_{\gamma}$, given by

$$
\begin{equation*}
X_{\gamma}=\int(1+z)^{\gamma} d z \tag{3.12}
\end{equation*}
$$

If no proximity effect existed, the number of lines per coevolving coordinate would be expressed as

$$
\begin{equation*}
d \mathcal{N} / d X_{\gamma}=\mathcal{A}_{0} \tag{3.13}
\end{equation*}
$$

In this analysis, we use a value for $\beta$ of 1.46 from of Hu et al. (1995) based upon high $\mathrm{S} / \mathrm{N}$, high resolution spectra of four QSOs at $\mathrm{z} \approx 3$, consistent with the value of 1.4 found by Dobrzycki \& Bechtold (1996), hereafter DB96, from simulations of Ly- $\alpha$ forest spectra in QSOs at $z \approx 3$. The value of this parameter is an important factor in the ionization model. B94 found that changing the adopted value of $\beta$ from 1.7 to 1.4 caused the derived value of $J_{-21}$ to decrease by a factor of $\sim 3$. Giallongo et al. (1996) find that a double power law provides a better fit to the observed column density distribution in their high resolution spectra than a single power law. The form of their double power law consists of a break at $N_{H I}=10^{14} \mathrm{~cm}^{-2}$ and values of $\beta$ above and below this break of 1.8 and 1.4 respectively. For this analysis, however, we will use a single power law, as the data of Hu et al. (1995) do not require the double power law form.

The procedure consists of assuming a form for $J\left(\nu_{0}\right)$ as a function of z , dividing the lines into the appropriate $\omega$ bins, and finding the parameters of the assumed form of $J\left(\nu_{0}\right)$ that gives the lowest $\chi^{2}$ between the binned data and the ionization model. Since no work to date has shown that $J\left(\nu_{0}\right)$ evolves significantly with redshift over the range of our sample objects, we will treat the case that $J\left(\nu_{0}\right)$ is constant over the redshift range of the data.

Figure 3.5 plots $\chi^{2}$ with respect to the constant $J\left(\nu_{0}\right)$ photoionization model versus $\log \left[J\left(\nu_{0}\right)\right]$ and Figure 3.6 plots the coevolving number density versus $\omega$ for the lowest $\chi^{2}$ value of $J\left(\nu_{0}\right)$ for each subsample. The results of this analysis are summarized in Table 3.4 and are discussed in more detail in Section 3.4.

### 3.2.4 Maximum Likelihood Analysis

In addition to the standard BDO analysis, we also used a maximum likelihood method outlined by KF93 to measure the extragalactic ionizing background in a manner that
avoids binning of the data. One constructs a likelihood function of the form

$$
\begin{equation*}
L=\prod_{a} f\left(N_{a}, z_{a}\right) \prod_{Q} \exp \left[-\int_{z_{\min }^{Q}}^{z_{\max }^{Q}} d z \int_{N_{\min }^{Q}}^{\infty} f(N, z) d N\right] \tag{3.14}
\end{equation*}
$$

where the subscripts $a$ and $Q$ refer to absorbers and QSOs and where $f(N, z)$ is the standard equation for the distribution of Lyman $\alpha$ absorbers in column density and redshift,

$$
\begin{equation*}
f(N, z)=A N^{-\beta}(1+z)^{\gamma}[1+\omega(z)]^{-(\beta-1)} . \tag{3.15}
\end{equation*}
$$

The parameter $\omega$ is defined as above, but here, the normalization in terms of $\mathcal{A}_{0}$ in Equation 3.1 is given by $\mathcal{A}_{0}\left(N_{\text {lim }} / N_{0}\right)^{\beta-1}(1 /(\beta-1))$. With the exception of the case in which a variable threshold is used, $N_{\text {min }}$ for each QSO is the column density which, according to the curve-of-growth adopted (see KF93), corresponds to an equivalent width of $0.32 \AA, 2.62 \times 10^{14} \mathrm{~cm}^{-2}$.

Instead of using the method outlined by KF93 whereby the parameters $A, \beta, \gamma$, and $J\left(\nu_{0}\right)$ are all found by minimizing $-\ln (\mathrm{L})$ where L is given by the likelihood function above, we chose to take the parameter $\gamma$ from a separate maximum likelihood solution to Equation 3.1 (see Paper I.) Since our spectra are more highly blended than the low redshift data used by KF93, we choose not to determine $\beta$ directly from our data using line equivalent widths and the curve-of-growth and instead adopt a value found from high resolution spectra. As described in the previous section, we take $\beta$ to be 1.46 (Hu et al. (1995) and solve for $A$ by requiring $f(N, z)$ to give the observed number of lines in the regions of the QSO spectra unaffected by the proximity effect.

We ran two tests on this set of algorithms. The first of these was to attempt to reproduce the results of KF93 with the dataset they used from Bahcall et al. (1993) . Next, we used a high redshift subsample of our complete dataset, the DB96 sample, to compare the results of the maximum likelihood analysis and the BDO analysis to each other and to independent checks on these values (B94, Giallongo et al. 1996).

We were able to reproduce the results of KF93. Using their Sample 2, the Bahcall et al. (1993) sample minus one BAL QSO, PG $0043+039$, we obtain $(\gamma, \beta, \log (\mathrm{A}))=$
( $0.23,1.47,7.74$ ) and $\log \left[J\left(\nu_{0}\right)\right]=-23.0_{-0.6}^{+0.7}$ for $b=35 \mathrm{~km} \mathrm{~s}^{-1}$. These agree with the values they find, $(\gamma, \beta, \log (A))=(0.21,1.48,7.74)$, and the errors in these values, $\sigma_{\gamma} \sim 0.06 \sigma_{\beta} \sim 0.05$, and $\sigma_{\log (A)} \sim 0.1$. Their result for $\log \left[J\left(\nu_{0}\right)\right]$ for this sample is $-23.3_{-0.5}^{+0.7}$.

The high redshift subsample we created consisted of 518 lines from the 15 objects from DB96 that do not show associated absorption. The QSOs have redshifts between 2.52 and 3.38. Using our maximum likelihood program to solve for the Ly$\alpha$ forest statistics, we find $\gamma=1.926 \pm 0.656$, and $\log (A)=7.03$ for $N_{\min }=2.6 \times$ $10^{14} \mathrm{~cm}^{-2}$ and $\beta=1.46$. This subsample does give similar results in the BDO and the maximum likelihood cases, $\log \left[J\left(\nu_{0}\right)\right]=-21.40_{-0.69}^{+1.10}$ and $\log \left[J\left(\nu_{0}\right)\right]=-21.58_{-0.23}^{+0.30}$, respectively. (See rows 1 and 2 of Table 3.4.) These values agree well with the Giallongo et al. (1996) result of $\log \left[J\left(\nu_{0}\right)\right]=-21.30 \pm 0.7$ for $z=1.7-4.1$.

The software we used for the maximum likelihood analysis uses all regions of the QSO spectra between $z_{\text {min }}$, specified by the spectral coverage or by Ly $\beta$ emission, and $z_{\max }$, specified by Ly- $\alpha$ emission. Though it does not count lines associated with identified metal line systems, it does not exclude the regions of the spectrum where these lines lie. To ensure that this does not have a significant effect on our resultant solution for the background, we tested a program that does exclude regions of the spectra in the same way that our BDO-style software does. The change in the result was indeed insignificant; but taking these excluded spectral regions into account and binning the data in the same way the BDO-style software does brings the maximum likelihood and the BDO method results into excellent agreement.

Figure 3.7 plots the $\log$ of the ratio of the likelihood function to the maximum value versus $\log \left[J\left(\nu_{0}\right)\right]$; and Figure 3.8 plots the coevolving number distribution of Ly- $\alpha$ lines with respect to $\omega$ just as in Figure 3.6. The results of this analysis are also summarized in Table 3.4 and discussed further in Section 3.4.

### 3.2.5 Systemic QSO Redshifts

One of the major uncertainties in the proximity effect analysis is in the systemic redshifts of the QSOs. If the true redshift of a QSO is higher than the value used in the analysis, any given cloud is further away from the QSO than assumed. Hence, the influence of the QSO at this cloud is less than inferred and the value of $J\left(\nu_{0}\right)$ in reality is lower than the one derived.

For the data presented in Figure 3.2, an average of several cursor settings at the peak of the emission line was used to determine the line centers. More detailed fits were not done as our purpose lies mainly in determining if any gross shifts between Ly- $\alpha$ and the Balmer lines/[OIII]/Mg II exist for our data; but we found no significant difference between this method and making Gaussian fits to the upper $50 \%$ of the emission line profiles.

Ly- $\alpha$ redshifts were measured from the absorption line spectra when the entire Ly- $\alpha$ profile was observed, in the same way as was done for the Balmer, [OIII], and Mg II lines. Table 3.5 lists the adopted best redshift value for each emission line for each object supplementing our measurements with measurements from the literature.

Laor et al. (1994) and Laor et al. (1995) found, from a sample of 13 QSO spectra from the Faint Object Spectrograph on Hubble Space Telescope between redshifts of $z \sim 0.16$ and $z \sim 2.0$, average velocity shifts between [OIII] $\lambda 5007$ and Ly- $\alpha$, Mg II, and $\mathrm{H} \beta$ of $200 \pm 150 \mathrm{~km} \mathrm{~s}^{-1},-85 \pm 130 \mathrm{~km} \mathrm{~s}^{-1}$, and $-75 \pm 110 \mathrm{~km} \mathrm{~s}^{-1}$, respectively. This agrees with the Corbin \& Boroson (1996) result for 48 objects with $0.03<z<0.77$. They found mean [OIII]-Ly- $\alpha$ and [OIII]-H $\beta$ shifts of $191 \pm 101 \mathrm{~km}$ $\mathrm{s}^{-1}$ and $-75 \pm 57 \mathrm{~km} \mathrm{~s}^{-1}$. Thus, Ly- $\alpha$ is blueshifted with respect to [OIII] by $\sim 200$ $\mathrm{km} \mathrm{s}^{-1}$, while Mg II and $\mathrm{H} \beta$ are marginally redshifted with respect to [OIII]. Tytler \& Fan (1992) find a mean [OIII]-H $\beta$ shift of $-15 \pm 37 \mathrm{~km} \mathrm{~s}^{-1}$ from 8 QSOs with redshifts between $\sim 0.3$ and $\sim 0.6$ and conclude that both Balmer lines and narrow forbidden lines give redshifts within $100 \mathrm{~km} \mathrm{~s}^{-1}$ or less of the QSO systemic redshift.

They then find a blueshift of Mg II with respect to $[\mathrm{OIII}] / \mathrm{H} \beta$ for 100 QSOs of $101 \pm 47$ $\mathrm{km} \mathrm{s}^{-1}$ which they use as a secondary systemic redshift zero point in their analysis of a large QSO sample. The magnitude of the blueshift of Ly- $\alpha$ with respect to [OIII]/H $\beta$ that they derive is $172 \pm 17 \mathrm{~km} \mathrm{~s}^{-1}$. The data of Nishihara et al. (1997) for five QSOs at $z \sim 1.5$ show a negligible redshift of Mg II with respect to [OIII], $31 \pm 411 \mathrm{~km} \mathrm{~s}^{-1}$. However these five objects show a somewhat larger redshift of $\mathrm{H} \beta$ with respect to [OIII] $\lambda 5007$, equalling $260 \pm 522 \mathrm{~km} \mathrm{~s}^{-1}$, consistent with the fact that these objects have high luminosities. M ${ }^{c}$ Intosh et al. (1999b) use the near-infrared spectra of QSOs at $2.0 \lesssim z \lesssim 2.5$ presented in M ${ }^{c}$ Intosh et al. (1999a) to examine the redshift differences between [OIII] and $\mathrm{H} \beta$. They supplement their data with data from the literature to measure the redshift differences between [OIII] and Mg II. They find that on average, $\mathrm{H} \beta$ is redshifted relative to [OIII] by $520 \pm 80 \mathrm{~km} \mathrm{~s}^{-1}$ for 21 of their sample objects, while Mg II lies within $50 \mathrm{~km} \mathrm{~s}^{-1}$ of the redshift of [OIII] for 12 sample objects.

For our sample, we find that Ly- $\alpha$ is blueshifted with respect to [OIII] $\lambda 5007$ by $382 \pm 1160 \mathrm{~km} \mathrm{~s}^{-1}$ for 19 QSOs. Mg II emission is blueshifted by an average of $338 \pm 901 \mathrm{~km} \mathrm{~s}^{-1}$ with respect to [OIII] on the basis of seven measurements. We find that $\mathrm{H} \beta$ is redshifted by $642 \pm 740 \mathrm{~km} \mathrm{~s}^{-1}$ with respect to [OIII] on the basis of five measurements; and including three $\mathrm{H} \alpha$ redshifts listed in Table 3.5 with these $\mathrm{H} \beta$ redshifts, leads to a $507 \pm 615 \mathrm{~km} \mathrm{~s}^{-1}$ redshift of Balmer lines with respect to [OIII]. This shift is larger than that discussed above for low reshift QSOs. However, it is consistent with the Nishihara et al. (1997) $\mathrm{H} \beta$ shift for high luminosity QSOs. Combining our data with that of these authors, we find that Mg II is blueshifted with respect to [OIII] by $184 \pm 735 \mathrm{~km} \mathrm{~s}^{-1}$; and including the data of $\mathrm{M}^{c}$ Intosh et al. (1999b) that is not already in our sample gives a blueshift of $95 \pm 603 \mathrm{~km} \mathrm{~s}^{-1}$. Similarly, combining our data with that of Nishihara et al. (1997), we find that $\mathrm{H} \beta$ is redshifted with respect to [OIII] by $451 \pm 636 \mathrm{~km} \mathrm{~s}^{-1}$; and after supplementing this combined data set with the data of $\mathrm{M}^{\mathrm{c}}$ Intosh et al. (1999b), the redshift becomes
$379 \pm 516 \mathrm{~km} \mathrm{~s}^{-1}$. Lastly, combining the data of $\mathrm{M}^{c}$ Intosh et al. (1999b) with ours gives a Ly- $\alpha$ blueshift of $418 \pm 920 \mathrm{~km} \mathrm{~s}^{-1}$ with respect to [OIII].

As has been noted in previous work, the standard error in the mean velocity shifts is quite large, on the order of or exceeding the value of the shift itself. We estimate that the wavelength calibration errors in our data contribute a $\sim 10-30 \mathrm{~km} \mathrm{~s}^{-1}$ error in the derived redshifts; and the spread in different redshift measurements of the same species (e.g. Balmer lines or [OIII] $\lambda 4959$ and $\lambda 5007$ ) for the same object is typically $100-200 \mathrm{~km} \mathrm{~s}^{-1}$. The observed spreads in the velocity differences of the $\mathrm{Ly}-\alpha, \mathrm{Mg}$ II, and Balmer emission lines with respect to the quasar systemic redshifts are much larger than this, indicating that it is intrinsic to the quasar population. Figure 3.9 shows histograms of the emission line redshift differences between [OIII] and Ly- $\alpha$, [OIII] and Mg II, and [OIII] and Balmer lines. Our results are plotted with those of Laor et al. (1995) and of Nishihara et al. (1997). Our sample shows no welldefined mean [OIII]-Balmer shift, just a large scatter in the measurements included. Our sample also shows a large range of [OIII]-Ly- $\alpha$ and [OIII]-Mg II shifts with no well-defined mean value. Nonetheless, the mean trend is that the [OIII]-Ly- $\alpha$ shift is different from zero by $1.4 \sigma$ for our data, less than the $3.5 \sigma$ significance found by Laor et al. (1995). The [OIII]-Balmer line shifts for both our data set and for our data combined with that of Nishihara et al. (1997) are more significant, $2.7 \sigma$ and $2.8 \sigma$ respectively. The [OIII]-Mg II shift is consistent with zero in a mean sense, but with large scatter. Thus, though better statistics are desirable, it seems that for these high redshift and relatively high luminosity objects, Balmer lines are not good indicators of the QSO systemic redshift. For the purposes of this study therefore, we treat only the redshifts found from [OIII] $\lambda 5007$ for 19 objects in our sample and Mg II for 16 objects in our sample as systemic QSO redshifts.

### 3.2.6 The HI Ionization Rate

The HI ionization rate due to a source of UV flux is formally given by the equation:

$$
\begin{equation*}
\Gamma=\int_{\nu_{0}}^{\infty} \frac{4 \pi J(\nu) \sigma_{H I}(\nu)}{h \nu} d \nu \mathrm{~s}^{-1} \tag{3.16}
\end{equation*}
$$

The calculations of the mean intensity of the ionizing background to date have made a critical assumption, namely that the spectrum of the background and the spectra of the individual QSOs are identical. This allows the expression $\omega=\Gamma^{Q} / \Gamma^{b g}$ to reduce to the ratio of the Lyman limit flux density of the QSO, $J^{Q}\left(\nu_{0}\right)$, to that of the background, $J^{b g}\left(\nu_{0}\right)$, for each line (BDO). Since the IGM reprocesses the radiation emitted from QSOs, this is not strictly true (Miralda-Escudé \& Ostriker 1990, Madau 1991,1992, Meiksin \& Madau 1993, Haardt \& Madau 1996, Fardal, Giroux, \& Shull 1998). Furthermore, the value of $\Gamma^{b 9}$ is of particular interest as it can be used to infer the value of $\Omega_{b}$ by comparing the distribution of flux decrements in high resolution QSO spectra to Lyman $\alpha$ forest simulations (Rauch et al. 1997). Therefore, we repeat the standard BDO analysis without making this assumption, ie. using $\omega=\Gamma^{Q} / \Gamma^{b g}$ and solving for the HI ionization rate from the metagalactic background radiation. The ionization rate for each QSO was calculated using Equation 3.16, where $\sigma_{H I}(\nu)=$ $6.3 \times 10^{-18}\left(\frac{\nu_{0}}{\nu}\right)^{3} \mathrm{~cm}^{2}$ and where $J^{Q}(\nu)=J^{Q}\left(\nu_{0}\right)\left(\frac{\nu}{\nu_{0}}\right)^{-a}$. For each QSO, $J^{Q}\left(\nu_{0}\right)$ is the same value used in the standard analysis used to solve for $J^{b g}\left(\nu_{0}\right)$, and $\alpha$ is given in Table 3.3. For some objects, no $\alpha$ listed in this table and a value of 0.46 was used, as described in Section 3.2.1. As before, the best value will be the one that gives the lowest $\chi^{2}$ between the model with $\beta=1.46$ and the binned data. We use the narrow line redshifts for each QSO discussed above and add $400 \mathrm{~km} \mathrm{~s}^{-1}$ to each QSO redshift measured from the Lyman $\alpha$ emission line.

Haardt \& Madau (1996) present a Gaussian fit to their model for the evolution of $\Gamma$ with redshift,

$$
\begin{equation*}
\Gamma=A(1+z)^{B} \exp \left[-\left(z-z_{c}\right)^{2} / S\right] \tag{3.17}
\end{equation*}
$$

that agrees with their detailed model for the background to within $10 \%$ over the range $0<z<5$. The best fit parameters they derive are $A=6.7 \times 10^{-13} \mathrm{~s}^{-1}$, $B=0.73, z_{c}=2.30$, and $S=1.90$. Fardal, Giroux, \& Shull (1998) fit their model for the background with the parameter sets $A=5.6 \times 10^{-13} \mathrm{~s}^{-1}, B=0.60, z_{\mathrm{c}}=2.22$, and $S=1.90$ and $A=1.26 \times 10^{-12} \mathrm{~s}^{-1}, B=0.58, z_{c}=2.77$, and $S=2.38$ for the Q1 and Q2 luminosity functions, of Pei (1995) respectively. Incorporating this expression for $\Gamma(z)$ with these three different sets of parameters into the BDO style analysis allows us to determine which of these models fits our data best. The results are listed in Table 3.6 and are discussed in greater depth below in Section 3.4.

### 3.3 Simulations and the Curve of Growth

Simulated Lyman $\alpha$ forest spectra for the DB96 sample only were produced using the software described in that paper. The simulation input $\gamma$ was changed slightly to reflect the maximum likelihood value found by the software used in the analysis described in Paper I. The normalization was chosen to give matching amounts of total absorption in the real and simulated spectra. The parameters used were $\gamma=2.069$, $\mathcal{A}_{0}=4.835, \beta=1.46, \log \left(\mathrm{~N}_{\mathrm{HI}_{\min }}\right)=13.0, \log \left(\mathrm{~N}_{\mathrm{HI}_{\text {max }}}\right)=16.0,<\mathrm{b}>=28.0 \mathrm{~km} \mathrm{~s}^{-1}$, $\sigma_{b}=10.0 \mathrm{~km} \mathrm{~s}^{-1}$, and $b_{\text {cut }}=20.0 \mathrm{~km} \mathrm{~s}^{-1}$.

The proximity effect was included in these simulations by simply modifying each cloud's column density according to equations 3.7 and 3.10 . The value of $\log \left[J\left(\nu_{0}\right)\right]$ from the BDO type analysis on the DB96 sample is $-21.40_{-0.69}^{+1.1}$. Values of $-19.0,-20.0$, $-21.3,-22.0$, and -23.0 for $\log \left[J\left(\nu_{0}\right)\right]$ were input and the analyses described above were used to recover that $J\left(\nu_{0}\right)$. Two examples of the simulated spectra are shown in Figure 3.10.

The analysis considers all lines above a fixed equivalent width threshold of 0.32 A . Thus, as the column densities of lines are modified by the QSO flux from their expected values in the absence of the proximity effect, the equivalent widths of the
lines will change according to the curve-of-growth. If a line is saturated, changing its column density will have little effect on its equivalent width, since it lies on the flat part of the curve-of-growth where $W \propto \sqrt{\log (N)}$. This will mean that for a given equivalent width cutoff in the data, this line will not drop out of the sample as the proximity effect is turned on in the simulations. Since the line deficit will be less than expected for a given input value of $J\left(\nu_{0}\right)$, the proximity effect will appear less pronounced and the true $J\left(\nu_{0}\right)$ will be overestimated. We found this to be the case from our simulations. As Figure 3.11 illustrates and Table 3.7 summarizes, though the values of $J\left(\nu_{0}\right)$ recovered from the simulated data were usually consistent with the input values within the $1 \sigma$ confidence limits, they were systematically larger than the input values by up to a factor of 3 . The largest input values of $\log \left[J\left(\nu_{0}\right)\right],-19.0$ and $\mathbf{- 2 0 . 0}$, give the largest discrepancy between this input value and the $\log \left[J\left(\nu_{0}\right)\right]$ recovered from the BDO analysis performed on the simulated spectra. The smallest input value of $\log \left[J\left(\nu_{0}\right)\right],-23.0$, gives the smallest discrepancy between the input and recovered values. However, the $1 \sigma$ confidence limits on this fit are also relatively small, making it the only trial which does not recover the input $\log \left[J\left(\nu_{0}\right)\right]$ to within those limits.

To demonstrate the effect, Figure 3.12 compares the simulated line equivalent widths with and without the proximity effect included. The column density of each line from the simulated spectra line lists with no proximity effect were modified according to equations 3.7 and 3.10 . Figures $12(\mathrm{a}-\mathrm{e})$ plot the non-proximity effect rest equivalent width $W_{n o-P E}$ versus the ratio of the proximity effect and non-proximity effect equivalent widths, $W_{P E} / W_{n o-P E}$. The solid line delineates the detection threshold for the lines in the list for which the proximity effect is included, $W_{P E}=0.32 \AA$. Absorption lines that fall above this line were not removed from the sample when the proximity effect was turned on, while those below it disappeared. For a given set of QSOs with fixed Lyman limit lumosities, such as this one, the proximity effect signature in their spectra will become less pronounced as the ambient UV background
increases. Therefore, as $\log \left[J\left(\nu_{0}\right)\right]$ increases from -23.0 to -19.0, the magnitude of the proximity effect decreases, and the pre- and post- proximity effect line lists differ less and less from each other.

### 3.4 Results and Discussion

Table 3.4 lists the best fit values of $J\left(\nu_{0}\right)$ found for various subsamples of this dataset using both the canonical BDO and the maximum likelihood methods. For the BDO method, the $1 \sigma$ confidence limits are found from a $\Delta \chi^{2}$ of 8.18 for 7 degrees of freedom. The maximum likelihood method $1 \sigma$ confidence limits derive from the fact that $\ln \left(L / L_{\max }\right)$ is distributed as $\chi^{2} / 2$. The total sample consisting of 74 QSOs with all QSO redshifts based on the Ly- $\alpha$ emission line gives a best fit value of $\log \left[J\left(\nu_{0}\right)\right]$ of $-20.90_{-0.48}^{+0.61}$ for the BDO analysis and $-20.83_{-0.20}^{+0.23}$ for the maximum likelihood analysis.

As the results in Table 3.4 demonstrate, using narrow line redshifts for 35 of the 74 QSOs for which they have been directly measured and Ly- $\alpha$ redshifts for the rest does not change the result. However, when $400 \mathrm{~km} \mathrm{~s}^{-1}$ is added to the Ly- $\alpha$ redshifts of the objects with no measured narrow line redshift, a value for $\log \left[J\left(\nu_{0}\right)\right]$ of $-21.15_{-0.43}^{+0.17}$ is derived using the BDO method and $\log \left[J\left(\nu_{0}\right)\right]=-21.17_{-0.15}^{+0.19}$ is found using the maximum likelihood method. Recall that the mean blueshift of Ly- $\alpha$ with respect to [OIII] for the 19 objects in this paper with [OIII] $\lambda 5007$ measurements was found to be $\sim 400 \mathrm{~km} \mathrm{~s}^{-1}$. This decrease in the mean intensity of the background derived when larger QSO redshifts are used is to be expected. (cf. Section 3.2.5) Because this measurement of the background accounts for the systematic blueshift of the Ly- $\alpha$ emission line with respect to the systemic redshift of each QSO, we consider it to be our best estimate for the mean intensity of the background at the Lyman limit.

These measurements have been made, however, using a photoionization model with somewhat unrealistic assumptions, particularly that $\mathrm{Ly}-\alpha$ absorbers are isother-
mal and are composed of pure hydrogen. For clouds with a primordial He abundance and which are in thermal and ionization equilibrium, Using CLOUDY to model the ionization state of absorbers with a metal adundance of $10^{-2}$ solar (Cowie et al. 1995, Tytler \& Fan 1994) as a function of $\omega$, we find that the neutral fraction, $\chi$, is proportional to $(1+\omega)^{-1.21}$. This implies that

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=\mathcal{A}_{0}(1+z)^{\gamma}[1+\omega(z)]^{-1.21(\beta-1)} \tag{3.18}
\end{equation*}
$$

In this scenario, the optimal value found for $\log \left[J\left(\nu_{0}\right)\right]$ is $-21.10_{-0.28}^{+0.53}$. This value is marginally larger than the value discussed above, found under the assumption of absorbers composed of pure hydrogen; but it is not significantly different, so we conclude that the absence of metals in the BDO model has not drastically affected our measurement of the background.

It is worth noting that 16 objects in our sample of objects with no associated absorption show evidence for damped Ly- $\alpha$ absorption: $0058+019,0100+130,0334-$ $204,0913+072,0938+119,0952+338,0955+472,1009+299,1017+280,1215+333$, $1247+267,1548+092,1946+770,2126-158,2233+131$, and $2320+079$. The dust in these systems could cause the intrinsic QSO fluxes to be underestimated. This in turn can cause $\log \left[J\left(\nu_{0}\right)\right]$ to be underestimated by up to a factor of 3 , in addition to the sources of error discussed above (Srianand \& Khare 1996). Only six of these objects, $0334-204,0938+119,0955+472,1215+333,2126-158$, and $2233+131$, appear in our low luminosity subsample, suggesting that this subsample is not preferentially heavily dust-obscured. Nevertheless, the BDO analysis was performed on all 16 objects exhibiting damped Ly- $\alpha$ systems; and found the best fit value for $\log \left[J\left(\nu_{0}\right)\right]$ to be $-21.45_{-0.53}^{+0.40}$, a factor of $1.9_{-1.6}^{+8.1}$ lower than the value obtained for the sample as a whole. This does not allow us to say anything significant about the presence or absence of dust, so we will neglect its influence.

Dividing our line sample into subsamples of high $(z>2.5)$ and low ( $z<2.5$ ) redshift lines, we find marginal evidence for evolution in the intensity of the background,
namely that the maximum likelihood background intensity is lower by a factor of about $1.9_{-1.4}^{+3.9}$ at lower redshift. The BDO results corroborate this, but with larger uncertainties. The factor by which $J\left(\nu_{0}\right)$ is found to be lower at lower redshifts is $2.5_{-2.2}^{+27.7}$. Gravitational lensing could mimic a trend with redshift with about the same order of magnitude, if the high redshift subsample contains a significant number of unknown lenses. However, Figure 3.3 suggests little if any trend for high luminosity objects to exist at high redshifts in our sample; and the results of Section 3.2.2 indicate that the high luminosity objects do show a somewhat stronger proximity effect despite the fact that the measured background at high redshift appears to be higher. No other studies have found this evidence of redshift evolution in the background, so we regard it as tentative; and note that it will be interesting to see in future work if this trend can be shown to be real and if it extends smoothly to the low values of $J\left(\nu_{0}\right)$ found at redshifts less than 1.5 .

Since we find high luminosity objects do not exist preferentially at high redshift in our sample, a simple test can be done to determine whether or not there is a significant number of lensed objects in our sample. If the high luminosity QSOs are indeed intrinsically more luminous, and the proximity effect is a purely photoionization-driven phenomenon, these objects should show a more prominent proximity effect. The results of Section 3.2.2 suggest this is the case. However, in the analysis, this larger line deficit is normalized to the higher Lyman limit luminosities of this subsample. Therefore, one expects these objects, when analyzed as a separate subsample, to yield a value of $J\left(\nu_{0}\right)$ that is consistent with that found for low luminosity objects if the values of the QSO fluxes are not in error due to lensing. If the high luminosity QSOs, or a subset of them, are lensed objects, then they are not necessarily intrinsically more luminous than the low luminosity QSOs. In this case, the influence of the lensed objects on the surrounding IGM will be overestimated and given the observed line deficit, the background will also be overestimated. Table 3.4 lists the results obtained for the high and low luminosity subsamples of our data set. The values obtained for
these subsamples are equal within the uncertainties. This is consistent with there being no significant effects from gravitational lensing in our sample.

### 3.4.1 HI Ionization Rate

We tested a range of values for $\Gamma$, the HI ionization rate, using our data. The constant value found to fit the data the best is $1.9_{-1.0}^{+1.2} \times 10^{-12} \mathrm{~s}^{-1}$. This value is in good agreement with that predicted by the QSO-dominated model of Haardt \& Madau (1996) at this redshift, $1.3 \times 10^{-12} \mathrm{~s}^{-1}$. Using Equation 3.16 and $J^{Q}(\nu)=J^{Q}\left(\nu_{0}\right)\left(\frac{\nu}{\nu_{0}}\right)^{-\alpha}$, and assuming global QSO spectral indicies of $0,1.5$, and 2 , the ionization rate found from our data corresponds to $\log \left[J\left(\nu_{0}\right)\right]=-21.34,-21.17$, and -21.12 , respectively.

The parameter set $\left(A, B, z_{c}, S\right)$ found to give the best fit to the data is that of Fardal, Giroux, \& Shull (1998) for the Q2 luminosity function ( $1.2 \times 10^{-12} \mathrm{~s}^{-1}, 0.58$, $2.38,2.77$ ) which, for a redshift of 2.9 yields an ionization rate of $2.7 \times 10^{-12} \mathrm{~s}^{-1}$, in good agreement with our solution, and within a factor of $\sim 2$ of the Haardt \& Madau result. Thus, we conclude that a significant contribution to the ionizing background from stellar UV emission is not required at this redshift.

### 3.4.2 Curve-of-Growth and Other Systematics

On the basis of a curve-of-growth argument, one might expect that weak lines would show a more prominent proximity effect than strong lines. We have compared the results obtained for a constant equivalent width threshold of $0.32 \AA$ with that obtained for lines with $0.16 \AA<W<0.32 \AA$. Instead of finding a more pronounced proximity effect for the weak lines, we find a less significant deficit of lines within $1.5 h^{-1} \mathrm{Mpc}$ of the QSOs. This deficit is $4.0 \sigma$, versus $5.5 \sigma$ for lines with $\mathrm{W}>0.32 \AA$. As Table 3.4 lists, the value of $\log \left[J\left(\nu_{0}\right)\right]$ recovered from these weak lines is correspondingly higher than that found using strong lines, $-20.45_{-0.90}^{+0.37}$ versus $-21.15_{-0.43}^{+0.17}$. Cooke et al. (1997) point out that this could be the result of a higher degree of blending of weaker
lines compared to strong ones in crowded spectral regions. The background flux measurement will be an overestimate because blending will cause fewer individual lines to be resolved further from the QSO. Because the reduction in line density near the QSO will work to reduce line blending, the overall effect of line blending will be to suppress the true magnitude of the proximity effect causing $J\left(\nu_{0}\right)$ to be overestimated, by a factor of 4.5 in this case. It is difficult to ascertain whether this effect is as strong for lines with $\mathrm{W}>0.32 \AA$ or whether the curve-of-growth effect discussed in Section 3.3 which also causes $J\left(\nu_{0}\right)$ to be overestimated, is more important. We expect that for lines with $\mathrm{W}>0.32 \AA$, the effects of blending are reduced somewhat, while the curve-of-growth effects will remain a factor.

We have addressed many of the systematics which could possibly have affected our analysis. A treatment of the quasar systemic redshifts was integrated directly into our analysis and was found to influence the $J\left(\nu_{0}\right)$ found by up to a factor of $\sim 2$. Other effects, such as the influences of metals and dust, which can cause $J\left(\nu_{0}\right)$ to be underestimated, and the influences of lensing, line blending, and curve-of-growth effects, which can cause $J\left(\nu_{0}\right)$ to be overestimated, were treated after the fact in an attempt to understand the magnitude of their effects on the value of $J\left(\nu_{0}\right)$ derived. The CLOUDY simulations discussed above indicate that allowing for an absorber metal abundance of $10^{-2}$ solar has little effect on the value of $J\left(\nu_{0}\right)$ found from the data. Dust in intervening absorption systems may have affected our result. Though we were unable to quantify this effect with high confidence, it could be on the order of a factor of 2 . We assert that QSO flux amplification due to lensing has not significantly biassed our result; and we attempt to minimize the effect of blending discussed above by using only lines with $\mathrm{W}>0.32 \AA$. Our result may be susceptible to the curve-of-growth effect we addressed through the simulations in Section 3.3. In those simulations, we found that the discrepancy between in the input and recovered values of $J\left(\nu_{0}\right)$ depended upong the input value of $J\left(\nu_{0}\right)$ itself. The magnitude of the discrepancy corresponding to the $J\left(\nu_{0}\right)$ we found from the data was a factor of
$\sim 2$. We therefore suspect that if our result, $\log \left[J\left(\nu_{0}\right)\right]=-21.15_{-0.43}^{+0.17}$, is systematically biased in any way, it is an overestimate of the true background and could be in error by up to a factor of 2 ; though this could be balanced somewhat by systematic error due to dust, which works in the opposite direction.

### 3.4.3 Comparison with Previous Measurements

Our value for $J\left(\nu_{0}\right)$ agrees well with other measurements at similar redshift, with the exception of those of B94 and Fernández-Soto et al. (1995) who both derive values four times larger than our best value for $J\left(\nu_{0}\right), \sim 3 \times 10^{-21} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1}$ $\mathbf{s r}^{-1}$. The measurement of B94 does not take into account QSO systemic redshifts, but she notes that if they are blueshifted with respect to $\mathrm{Ly}-\alpha$ by $1000 \mathrm{~km} \mathrm{~s}^{-1}$, this would lower the derived value of $J\left(\nu_{0}\right)$ by a factor of 3 , bringing it into reasonable agreement with our result. The Fernández-Soto et al. (1995) value is derived from 3 QSO spectra showing a proximity effect due to foreground QSOs. These authors are not able to place an upper limit on their measurement, but our value of $7.0 \times$ $10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ for $J\left(\nu_{0}\right)$ is consistent with their lower limit of $1.6 \times$ $10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$. In fact, when these authors examine the proximity effect in a single QSO spectrum due to the background $z \sim 2$ QSO itself, they derive a value for $J\left(\nu_{0}\right)$ of $7.9_{-6.0}^{+23} \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$, which brings their estimate into better agreement with our values for our total sample and for our low redshift subsample within their large errors. Direct measurements of the background at redshifts $\sim 3-3.5$ have been made using long-slit spectroscopy of fields containing optically thick Ly- $\alpha$ absorbers in efforts to detect fluorescent emission the absorbers produce from the ionizing radiation field incident upon them (Lowenthal et al. 1990, Martínez-González et al. 1995). Recent Keck telescope observations by Bunker et al. (1998) at $2.5<z<4.1$ have achieved a factor of 2-10 higher sensitivity and place a firmer direct limit on the background than previous work. Their null signal in a

90 -minute integration with a $3^{\prime}$ slit sets an upper limit on $J\left(\nu_{0}\right)$ of $2 \times 10^{-21} \mathrm{ergs} \mathrm{s}^{-1}$ $\mathrm{cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$.

Cooke et al. (1997) claim that the value for the background at $z \sim 4$ is between their value of $8.0_{-4.0}^{+8.0} \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ and that of Williger et al. (1994), $1.0-3.0 \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$. Our best value of $J\left(\nu_{0}\right)$ at $z \sim 3$, $7.0 \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$, is in agreement with this, although within the uncertainty there is an allowance for the background to decrease as $z$ approaches 4 .

Table 3.8 lists these various measurements of $J\left(\nu_{0}\right)$ in the literature as well as the Kulkarni \& Fall (1993) measurement at $z \sim 0.5$. Figure 3.13 also summarizes the literature measurements of $J\left(\nu_{0}\right)$ from $z \sim 0.5$ to $z=4.5$.

The solid curves in Figure 3.13 delineate the evolution of the mean background intensity as a function of redshift for global background source spectral indicies between 0 and 2, derived from the Haardt \& Madau (1996) model for the HI photoionization rate as a function of redshift discussed in Section 3.2.6. Over $90 \%$ of our sample QSO redshifts lie within the FWHM of the Gaussian in the Haardt \& Madau (1996) expression using their best fit parameters. At these redshifts, the Haardt \& Madau (1996) curves in Figure 3.13 are turning over. Nonetheless, for comparison with previous work (B94 and references therein), we investigate a power law redshift dependence of the background intensity:

$$
\begin{equation*}
J\left(\nu_{0}, z\right)=J\left(\nu_{0}, 0\right)(1+z)^{j} \tag{3.19}
\end{equation*}
$$

Using the BDO method, we executed a crude grid search in an attempt to constrain the power law index and normalization of this power law. The lowest $\chi^{2}(3.86)$ between the binned data and the BDO photoionization model for a power law background was achieved by $\left(j, \log \left[J\left(\nu_{0}, 0\right)\right]\right)=(5.12,-23.97)$, shown by a dashed line in Figure 3.14. Extending this solution to low redshift gives $\left.\log \left[J\left(\nu_{0}\right), 0.5\right)\right]=-23.0$, in good agreement with the measurement of Kulkarni \& Fall (1993). The solution $\left(j, \log \left[J\left(\nu_{0}, 0\right)\right]\right)=(-4.16,-18.76)$ gives the next lowest $\chi^{2}(4.91)$; and though it also
implies mean background intensities over four orders of magnitude too high at low redshift, it traces the Haardt \& Madau model at high redshift, giving $\log \left[J\left(\nu_{0}, 4.5\right)\right]=-$ 21.8, in agreement with the Willigher et al. (1994) measurement. It is also shown by a dashed line in Figure 3.14. Fitting parabolas to the regions near the $\chi^{2}$ minima in both $j$ and $\log \left[J\left(\nu_{0}, 0\right)\right]$ gives the error in each parameter for both of these solutions, ( $5.12 \pm 1.96,-23.97 \pm 1.07$ ) and ( $-4.16 \pm 2.36,-18.76 \pm 1.31$ ). B94 found a similarly large range of acceptable solutions: $-7<j<4$ and $-16.5<\log \left[J\left(\nu_{0}, 0\right)\right]<-23.0$. The large error bars on these fits indicate that the power law fit to the data is not well-constrained, due possibly to the fact that the mean intensity of the background is turning over at the redshifts of our sample objects, as the Haardt \& Madau (1996) model predicts.

### 3.4.4 Comparison with Models for the Background

Recent models of the ionizing background include not only the integrated emission from quasars but also a variety of other physical processes such as star formation in young, high redshift galaxies and attenuation of UV photons by Ly- $\alpha$ absorbers and Lyman limit systems (Miralda-Escudé \& Ostriker 1990, Madau 1991, 1992, Meiksin \& Madau 1993, Haardt \& Madau 1996, Fardal, Giroux, \& Shull 1998). Madau \& Shull (1996) find that the production of metals in Ly- $\alpha$ absorbers may also be a significant contributor to the UV background at $z \approx 3$. Their contribution may be up to $5 \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$, assuming that the bulk of the metals in the Lyman $\alpha$ forest did not form at $z \gg 3$, and assuming a Lyman continuum escape fraction, $f_{\text {esc }}$, from a galaxy of $\gtrsim 0.25$. They note, however, that $f_{\text {esc }}$ is essentially unconstrained.

Past debate about how the space density of quasars evolves at high redshift (Koo \& Kron 1988; Boyle et al. 1991; Irwin et al. 1991; Schmidt et al. 1991; Warren et al. 1994; Kennefick et al. 1995) has been clarified by recent radio surveys (Hook et al.

1995, 1998; Shaver et al. 1996). This work has demonstrated that the space density of radio-loud quasars decreases rapidly with redshift beyond $z \sim 3$. Since these surveys are unaffected by any presence of dust in the intervening IGM; and since they confirm the behavior seen in optically selected surveys, they indicate that the quasar population is truly declining at high redshift. Nevertheless, the discovery of QSOs with redshifts greater than 4 has brought better agreement between the values of $J\left(\nu_{0}\right)$ found via the proximity effect and the values predicted by the models with quasars primarily contributing to the background (Madau 1992, Meiksin \& Madau 1993, Haardt \& Madau 1996).

Madau (1992) and Meiksin \& Madau (1993) estimate the QSO UV background by integrating the QSO luminosity function (Boyle 1991) and including the effects of attenuation by hydrogen in the IGM. Their estimates however, $1-3 \times 10^{-22}$ ergs $\mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$, are still somewhat lower than the values derived in this paper. The analysis of Haardt \& Madau (1996) takes into account the effects of various atomic processes leading to the production of hydrogen-ionizing photons within Ly- $\alpha$ absorbers and Lyman limits systems themselves. They conclude that observed QSOs can account for number of ionizing photons required by the proximity effect at $z \lesssim 4$. These authors find a value of $\log \left[J\left(\nu_{0}\right)\right]$ equal to $\sim-21.2$ at $z=3$, in good agreement with the value found in this paper at similar redshifts. The solid lines in Figure 3.13 show the results from the Haardt \& Madau (1996) model for two different values of the global background source spectral index. The lower and upper curves show the evolution of the background for indicies of 0 and 2 respectively. The literature measurements at redshifts between 1.7 and 3.6 agree well with the model predictions. The $z \sim 0.5$ measurement of Kulkarni \& Fall (1993) falls below both model curves and the $z=4.5$ measurement of Williger et al. (1994) falls above them.

Madau, Haardt, \& Rees (1998) revisit the issue of the contribution of high redshift, star-forming galaxies to the ionizing background in light of recent work identifying such objects at $2<z<4$. (Steidel et al. 1996a,b; Madau et al. 1996; Lowenthal
et al. 1997) They calculate the critical photoionization rate necessary to reionize a non-uniform intergalactic medium as a function of redshift. This is compared to the expected contributions from quasars and young, star-forming galaxies. There are uncertainties in estimating both of these. The quasar luminosity function at $z>4$ must be extrapolated from that at lower redshifts. There is also still some debate between theory and observations, eg. of the Hubble Deep Field, on the subject of a population of low-luminosity QSOs (see Madau et al. 1998 and references therein) which could cause the quasar luminosity function to steepen with lookback time, making up for the dearth of observed objects at $z>4$. The estimation of the galaxy contribution of ionizing photons is limited by poor knowledge of luminosity function of Lyman-break galaxies at $z>4$ as well as by the lack of constraints upon $f_{\text {esc }}$. Nevertheless, the results are intriguing. Assuming that $f_{\text {esc }}=0.5$, Madau et al. (1998) find that the contribution of hydrogen-ionizing photons from star-forming galaxies $z \sim 3$ could exceed that from quasars by a factor of more than 3 . However, the quasar contribution at this redshift is sufficient, according to these estimates, to ionize the IGM at this redshift. Deharveng et al. (1998) estimate a much lower $f_{\text {esc }}$ at $z=0$, less than $1 \%$, based on the local galaxy $\mathrm{H} \alpha$ luminosity density. Furthermore, Devriendt et al. (1998) make an independent estimation of the galaxy contribution to $J\left(\nu_{0}\right)$ assuming damped Ly- $\alpha$ systems to be the progenitors of present day galaxies. Their semi-analytic models include a treatment of not only HI absorption of Lyman limit photons in the intervening IGM, but also of HI and dust absorption in the interstellar medium of the photon-producing galaxies. Their results show that constraining $f_{\text {esc }}$ in this way yields a much lower contribution to the UV background from galaxies at $z>2$. At $z \sim 2.5$, their estimated quasar contribution to $J\left(\nu_{0}\right)$ is 3 orders of magnitude greater than that expected from galaxies. Our measurement of $J\left(\nu_{0}\right)$ is consistent with the UV background being quasar-dominated in the models of both these authors and Haardt \& Madau (1996).

In the models of Madau et al. (1998), the scenario changes at $z \gtrsim 3.5$. At this
redshift, the quasar contribution of ionizing photons falls below the critical limit needed to photoionize the IGM; and by $z=5$, it will fall short of the critical value by a factor of $\sim 4$. This implies that at high redshift, the contribution from young stars may become the dominant contributor to the background, with the caveat that the space density of star-forming galaxies would have to be maintained at the level observed at $z \approx 3$, and that most of their UV photons would have to be free to escape into the IGM. The Devriendt et al. (1998) models lead to the conclusion, however, that the galaxy contribution to the UV background is negligible at high redshifts.

In conclusion, the proximity effect data at present reflect that the UV background at $2<z<4$ is quasar dominated. The discrepancies between this model at low and high redshifts (Kulkarni \& Fall 1993, Williger et al. 1994) indicate that the contribution to the background from galaxies may be of larger relative importance. We plan to undertake an analysis of the proximity effect at low redshifts from a large sample of quasar spectra taken with the Faint Object Spectrograph on the Hubble Space Telescope to place better constraints on the background at $0.5<z<2$. Further observations of objects at $z>4$ are also of particular interest to this subject.

TABLE 3.1. Spectrophotometry Observations of $z \approx 2$ QSOs

| QSO | Date | Exposure <br> (seconds) | Airmass | Wavelength Coverage <br> $(\AA)$ |
| :--- | :---: | :---: | :---: | :---: |
| $0006+020$ | 29Nov1994 | 1800 | 1.15 | $3150-6385$ |
| $0027+018$ | 22Sep1992 | 1800 | 1.28 | $3467-6475$ |
| $0037-018$ | 29Nov1994 | 2400 | 1.27 | $3150-6385$ |
| $0049+007$ | 29Nov1994 | 1800 | 2.05 | $3125-6380$ |
| $0123+257$ | 29Nov1994 | 1800 | 1.55 | $3125-6380$ |
| $0153+744$ | 29Nov1994 | 1800 | 1.38 | $3125-6380$ |
| $0348+061$ | 22Sep1992 | 1800 | 1.13 | $3465-6475$ |
| $1323-107$ | 28Mar1995 | 1800 | 1.56 | $3115-6400$ |
| $1346-036$ | 28Mar1995 | 1800 | 1.27 | $3115-6400$ |
| $1422+231$ | 22Apr1996 | 1800 | 1.31 | $5235-7554$ |
| $1603+383^{a}$ | 04July1995 | 450 | 1.03 | $3663-7544$ |
| $2134+004$ | 22Sep1992 | 1800 | 1.29 | $3465-6483$ |
| $2251+244$ | 29Nov1994 | 1800 | 1.01 | $3150-6385$ |
| $2254+022$ | 22Sep1992 | 1800 | 1.18 | $3470-6480$ |

${ }^{a}$ spectrum donated by Hamburg/CfA Bright Quasar Survey
(Dobrzycki,Engels, \& Hagen 1999) in advance of publication
Note- Instrument Set-up for:
$1422+231-\mathrm{SO} \mathrm{B} \mathrm{\& C} ,600 \mathrm{I} \mathrm{mm}^{-1} 1^{\text {st }}$ order, $\lambda_{b}=6681 \AA, 1.5^{\prime \prime}$ slit $1603+383-$ FLWO FAST, $300 \mathrm{I} \mathrm{mm}^{-1} 1^{\text {st }}$ order, $\lambda_{b}=4750 \hat{A}, 3^{\prime \prime}$ slit

Table 3.2. Summary of Narrow Emission Line Observations of $z \approx 2$ QSOs

| Name | V | Instrument | Date | Exposure (sec.) | Wavelength Coverage |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $0000-263$ | 17.5 | OSIRIS | 27Jul1994 | 4800 | $1.20 \mu \mathrm{~m}-1.46 \mu \mathrm{~m}$ |
| $0014+813$ | 16.5 | CRSP | 07Dec1993 | 1200 | $1.18 \mu \mathrm{~m}-1.26 \mu \mathrm{~m}$ |
|  |  | FSpec | 26Nov1993 | 5280 | $1.96 \mu \mathrm{~m}-2.39 \mu \mathrm{~m}$ |
| $0114-089$ | 17.4 | CRSP | 04Dec1993 | 3180 | $1.10 \mu \mathrm{~m}-1.35 \mu \mathrm{~m}$ |
| $0636+680$ | 19.0 | CRSP | 04Dec1993 | 4800 | $1.09 \mu \mathrm{~m}-1.35 \mu \mathrm{~m}$ |
|  |  | CRSP | 05Dec1993 | 2820 | $1.96 \mu \mathrm{~m}-2.10 \mu \mathrm{~m}$ |
| $0836+710$ | 16.5 | B\&C | 29Mar1995 | 1800 | $5250 \AA-9600 \AA$ |
| $0956+122$ | 17.5 | CRSP | 04Dec1993 | 8220 | $1.10 \mu \mathrm{~m}-1.35 \mu \mathrm{~m}$ |
|  |  | FSpec | 27Nov1993 | 5280 | $1.96 \mu \mathrm{~m}-2.38 \mu \mathrm{~m}$ |
| $1159+124$ | 17.5 | CRSP | 05Dec1993 | 3180 | $1.09 \mu \mathrm{~m}-1.35 \mu \mathrm{~m}$ |
|  |  | FSpec | 29Nov1993 | 4320 | $1.97 \mu \mathrm{~m}-2.38 \mu \mathrm{~m}$ |
| $1207+399$ | 17.5 | FSpec | 21May1994 | 600 | $1.98 \mu \mathrm{~m}-2.41 \mu \mathrm{~m}$ |
| $1208+101$ | 17.5 | CRSP | 06Dec1993 | 4800 | $2.00 \mu \mathrm{~m}-2.42 \mu \mathrm{~m}$ |
| $1408+009$ | 18.0 | FSpec | 02Apr1996 | 3840 | $1.46 \mu \mathrm{~m}-1.73 \mu \mathrm{~m}$ |
|  |  |  | 02Apr1996 | 1920 | $1.99 \mu \mathrm{~m}-2.40 \mu \mathrm{~m}$ |
| $1422+231$ | 16.5 | FSpec | 21May1994 | 1920 | $1.98 \mu \mathrm{~m}-2.41 \mu \mathrm{~m}$ |
| $1435+638$ | 15.0 | FSpec | 02Apr1996 | 1920 | $1.99 \mu \mathrm{~m}-2.40 \mu \mathrm{~m}$ |
| $2126-158$ | 17.3 | CRSP | 05Dec1993 | 3180 | $1.08 \mu \mathrm{~m}-1.35 \mu \mathrm{~m}$ |
|  |  | OSIRIS | 24Sep1994 | 7680 | $1.96 \mu \mathrm{~m}-2.35 \mu \mathrm{~m}$ |

Table 3.3: Spectrophotometric Properties of $z \approx 2$ QSOs

| QSO | $\mathrm{N}_{H I}\left(10^{20} \mathrm{~cm}^{-2}\right)$ | $\mathrm{f}_{\nu}^{\text {chs }}(912 \AA)$ | $\alpha$ | $\mathrm{f}^{\text {cos }}$ | $\mathrm{f}_{\nu}(912 \AA)$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (a) | (b) | (c) | (d) | (e) | (f) | (g) |
| 0006+020* | 3.02 |  | 0.26 | 354 (1450 $\AA$ ) | 313 | 1 |
| 0027+014 | 2.93 |  | -0.38 | 219 (1450 $\AA$ ) | 183 | 1 |
| 0037-018 | 2.81 |  | -0.27 | 45 (1450 $\AA$ ) | 51 | 1 |
| 0049+007 | 2.67 |  | 0.31 | 324 (1450 A) | 280 | 1 |
| 0123+257* | 6.88 |  | 1.12 | 237 (1450 $\AA$ ) | 141 | 1 |
| 0150-202* | 1.29 |  |  | 529 (1430 A ) | 430 | 2,3 |
| 0153+744* | 22.74 |  | 0.18 | 1023 (1450 $\AA$ ) | 940 | 1 |
| 0226-038 | 2.35 |  |  | 582 (1800 $\AA$ ) | 425 | 4 |
| 0348+061 | 12.33 |  | 0.12 | 513 (1450 $\AA$ ) | 485 | 1 |
| $0400+258$ | 7.82 |  | 1.54 |  | 199 | 5 |
| 0747+610 | 4.77 |  |  | 500 (1800 $\AA$ ) | 365 | 4 |
| 0819-032 | 6.16 |  | 0.33 | 63 (1450 $\AA$ ) | 54 | 6 |
| 0836+710* | 2.93 |  |  |  | 652 |  |
| 0848+155 | 3.14 |  | 0.07 | 198 (1450 $\AA$ ) | 191 | 7,8 |
| $0936+368$ | 1.36 |  |  |  | 386 |  |
| 0952+335 | 1.37 |  |  |  | 370 |  |
| 0955+472* | 1.04 |  |  |  | 188 |  |
| 0956+122 | 3.10 | 140 | 0.49 | 448 (1450 $\AA$ ) | 356 | 9 |
| 1009+299 | 2.30 |  |  |  | 1217 |  |
| $1207+399$ | 2.10 |  | 0.59 | 319 (1450 $\AA$ ) | 242 | 1,8 |
| 1210+175* | 2.67 |  |  |  | 285 |  |
| 1231+294 | 1.54 |  |  |  | 980 |  |
| 1323-107 | 2.64 |  | -0.30 | 303 (1450 $\AA$ ) | 349 | 1 |
| 1329+412* | 0.99 |  | 0.33 |  | 750 | 10 |

Table 3.3: Spectrophotometric Properties of $z \approx 2$ QSOs
(Continued)

| QSO | $\mathrm{N}_{\mathrm{III}}\left(10^{20} \mathrm{~cm}^{-2}\right)$ | $\mathrm{f}_{\nu}^{\text {bs }}(912 \AA)$ | $\alpha$ | $\mathrm{f}_{\nu}^{\text {bos }}$ | $\mathrm{f}_{\nu}(912 \AA)$ | Ref. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (a) | (b) | (c) | (d) | (e) | (f) | (g) |
| 1337+285* | 1.17 |  |  |  | 339 |  |
| 1346-036 | 2.51 |  | 0.091 | 458 (1450 $\AA$ ) | 439 | 1 |
| 1358+115* | 1.81 |  | 1.10 | 345 (1450 $\AA$ ) | 207 | 6 |
| $1406+492$ | 1.77 |  |  |  | 392 |  |
| $1408+009$ | 3.04 |  | 0.91 | 99 (1450 $\AA$ ) | 64 | 1 |
| $1421+330$ | 1.23 | 58 | 0.54 | 914 (1450 $\AA$ ) | 711 | 11,7 |
| 1422+231* | 2.52 |  | -1.21 | 211 (1450 $\AA$ ) | 371 | 1 |
| $1435+638$ | 1.68 | 55 |  | 1244 (1800 $\AA$ ) | 909 | 12,4 |
| 1603+383* | 1.32 |  | 0.36 | 550 (1450 $\AA$ ) | 464 | 1,13 |
| $1604+290$ | 3.24 |  |  |  | 428 |  |
| $1715+535$ | 2.69 | 36 | 1.26 | 875 (1800 $\AA$ ) | 371 | 11,10,4 |
| $2134+004$ | 4.03 |  | 0.04 | 35 (1450 $\AA$ ) | 34 | 1,14 |
| $2251+244 *$ | 5.18 |  | 1.53 | 243 (1450 $\AA$ ) | 119 | 1 |
| $2254+024$ | 5.32 |  | 0.20 | 116 (1450 $\AA$ ) | 106 | 1 |
| 2310+385 | 10.62 |  |  |  | 419 |  |
| 2320+079 | 5.04 |  |  |  | 306 |  |
| 2329-020 | 4.45 |  |  |  | 451 |  |

Table 3.3: Spectrophotometric Properties of $z \approx 2$ QSOs (Continued)

| QSO | $\mathrm{N}_{\mathrm{HI}}\left(10^{20} \mathrm{~cm}^{-2}\right)$ | $\mathrm{f}_{\nu}^{\mathrm{obs}(912 \AA)}$ | $\alpha$ | f $_{\nu}^{\text {obs }}$ | $\mathrm{f}_{\nu}(912 \AA)$ | Ref. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (a) | (b) | (c) | (d) | (e) | (f) | (g) |

${ }^{\text {a }}$ QSO name: an asterisk denotes a metal line system within $5000 \mathrm{~km} \mathrm{~s}^{-1}$ of the QSO emission redshift; in the case of $1422+231$, the QSO is a known lens
${ }^{6}$ Galactic $N_{H I}$ in units of $10^{20} \mathrm{~cm}^{-2}$ from program COLDEN using Stark et al. (1992)
${ }^{c}$ Observed flux in $\mu \mathrm{Jy}$ at the Lyman limit from reference in (g)
${ }^{d}$ Observed spectral index between Ly $\alpha$ and C IV emission lines or in the vicinity of the flux listed in (e) from reference in (g); in general, values are based upon spectra corrected for Galactic reddening if $\mathrm{E}(\mathrm{B}-\mathrm{V}) \gtrsim 0.03$
"Observed flux in $\mu \mathrm{Jy}$ at the rest wavelength indicated in parentheses from reference in ( g )
${ }^{f}$ Extrapolated Lyman limit flux in $\mu \mathrm{J}$ y from measured flux in (e), when available, or V magnitude given in Table 1 of Paper I.; if no observed spectral index available, value of 0.46 used (Francis 1996)
${ }^{9}$ References:
(1) this paper; (2) MacAlpine \& Feldman 1982; (3) Griffith et al. 1994; (4) Steidel \& Sargent 1991; (5) Cheng, Gaskell, \& Koratkar 1991; (6) Pei, Fall, \& Bechtold 1991; (7) Uomoto 1984; (8) Barthel et al. 1988; (9) Sargent, Steidel, \& Boksenberg 1989; (10) Baldwin, Wampler, \& Gaskell 1989; (11) Koratkar, Kinney, \& Bohlin 1992; (12) Lanzetta, Turnshek \& Sandoval 1993; (13) Hamburg QSO Survey (unpublished); (14) Perez, Penston, \& Moles 1989

Table 3.4: Measurements of $J\left(\nu_{0}\right)$

| Sample <br> (a) | $\overline{\mathcal{N}_{\text {lines }}}$ <br> (b) | $\gamma$, norm. <br> (c) | method <br> (d) | $\overline{\log \left[\left(J\left(\nu_{0}\right)\right]\right.}$ <br> (e) | $\begin{aligned} & \chi^{2} \\ & (\mathrm{f}) \end{aligned}$ | $\begin{gathered} \hline \hline \mathcal{N}_{\text {points }} \\ (\mathrm{g}) \\ \hline \end{gathered}$ | $\overline{\mathrm{Q}_{x^{2}}}$ <br> (h) | Figure <br> (i) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 518 | 1.9260,5.8882 | BDO | -21.40 ${ }_{-0.69}^{+1.1}$ | 3.05 | 7 | 0.88 | 6(a) |
| 1 | 518 | 1.9260,3.9709 | ML | $-21.58_{-0.23}^{+0.30}$ | 20.3 | 6 | 0.0024 | 8(a) |
| 2 | 1286 | 1.6749,7.5723 | BDO | -20.90 ${ }_{-0.48}^{+0.61}$ | 5.22 | 7 | 0.63 | 6(b) |
| 2 | 1286 | 1.6749,4.6637 | ML | $-20.83_{-0.20}^{+0.23}$ | 6.32 | 6 | 0.38 | 8(b) |
| 3 | 1286 | 1.6749,7.5723 | BDO | $-21.00_{-0.36}^{+0.57}$ | 7.19 | 7 | 0.40 | 6(c) |
| 3 | 1286 | 1.6749,4.6709 | ML | $-20.83_{-0.22}^{+0.24}$ | 7.41 | 6 | 0.28 | 8(c) |
| 4 | 1286 | 1.6749,7.5723 | BDO | $-21.15_{-0.43}^{+0.17}$ | 6.54 | 7 | 0.47 | 6(d) |
| 4 | 1286 | 1.6749,4.6617 | ML | $-21.17_{-0.15}^{+0.19}$ | 3.53 | 6 | 0.73 | 8(d) |
| 5 | 763 | -0.2848,110.13 | BDO | $-20.75_{-0.86}^{+0.16}$ | 3.31 | 7 | 0.85 | 6(e) |
| 5 | 763 | -0.2848,69.934 | ML | -21.18 ${ }_{-0.21}^{+0.19}$ | 4.92 | 5 | 0.42 | 8(e) |
| 6 | 523 | 1.3754,10.240 | BDO | $-21.15_{-0.92}^{+0.11}$ | 3.97 | 7 | 0.78 | 6(f) |
| 6 | 523 | 1.3754,7.4759 | ML | $-21.46{ }_{-0.29}^{+0.34}$ | 15.5 | 6 | 0.016 | 8(f) |
| 7 | 261 | 2.3284,2.6809 | BDO | $-21.45{ }_{-0.53}^{+0.40}$ | 3.03 | 7 | 0.88 | 6(j) |
| 8 | 666 | 1.5361,9.1237 | BDO | $-21.25_{-0.45}^{+0.28}$ | 4.32 | 7 | 0.74 | 6(g) |
| 9 | 620 | 2.0242,4.6980 | BDO | $-21.05_{-0.42}^{+0.20}$ | 3.49 | 7 | 0.83 | 6(h) |
| 10 | 671 | 0.5468,24.655 | BDO | $-20.45_{-0.90}^{+0.37}$ | 3.05 | 7 | 0.88 | 6(i) |

Table 3.4: Measurements of $J\left(\nu_{0}\right)$ (Continued)

| Sample <br> (a) | $\mathcal{N}_{\text {lines }}$ <br> (b) | $\gamma$, norm. <br> (c) | method <br> (d) | $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ <br> (e) | $\chi^{2}$ | $\begin{gathered} \hline \mathcal{N}_{\text {points }} \\ (\mathrm{g}) \\ \hline \end{gathered}$ | $Q_{x^{2}}$ <br> (h) | Figure <br> (i) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

${ }^{a}$ (1) DB96 sample;
${ }^{b}$ number of Ly $\alpha$ forest lines in sample
${ }^{c}$ Equ. 3.1 parameters $\gamma$ and $\mathcal{A}_{0}$ from maximum likelihood fit to data; when the method listed is ML, the normalization listed is equal to $\mathcal{A}_{0}\left(N_{\text {lim }} / N_{0}\right)^{\beta-1}(1 /(\beta-1))$ (see text,Paper I)
${ }^{d}$ BDO- Bajtlik, Duncan, \& Ostriker (1988),
ML- maximum likelihood, see Kulkarni \& Fall (1993)
${ }^{e}$ Best fit value of $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ in units of ergs s${ }^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$
${ }^{\prime} \chi^{2}$ of data versus the ionization model used
${ }^{g}$ number of points used to calculated $\chi^{2}$
${ }^{n} \chi^{2}$ probability for the ionization model used
${ }^{i}$ Figure displaying number distribution per coevolving redshift interval, $d \mathcal{N} / d X_{\gamma}$

Table 3.5: QSO Emission Line Redshifts for $J\left(\nu_{0}\right)$ Measurement ${ }^{a}$

| QSO | z | line $^{\text {b }}$ | Ref. ${ }^{\text {c }}$ |
| :---: | :---: | :---: | :---: |
| 0000-263* | 4.111 | Ly $\alpha$ | 1 |
|  | 4.116 | Mg II | 2 |
| 0001+087 | 3.243 | Ly $\alpha$ | 3 |
| 0002+051 | 1.899 | Ly $\alpha$ | 4 |
|  | 1.899 | Mg II | 5 |
| 0002-422 | 2.763 | Ly $\alpha$ | 6 |
| 0006+020* | 2.340 | Ly $\alpha$ | 2 |
| 0014+813 | 3.386 | Ly $\alpha$ | 1 |
|  | 3.379 | Mg II | 2 |
|  | 3.404 | $\mathrm{H} \beta$ | 2 |
| 0027+014 | 2.333 | Ly $\alpha$ | 2 |
|  | 2.310 | $\mathrm{H} \beta$ | 7 |
| 0029+073 | 3.261 | Ly $\alpha$ | 1 |
| 0037-018 | 2.341 | Ly $\alpha$ | 2 |
| 0049+007 | 2.275 | Ly $\alpha$ | 2 |
|  | 2.279 | [OIII] $\lambda 5007$ | 8 |
| 0058+019 | 1.959 | Ly $\alpha$ | 9 |
|  | 1.964 | Mg II | 5 |
| $0100+130$ | 2.690 | Ly $\alpha$ | 6 |
| 0114-089 | 3.194 | Ly $\alpha$ | 9 |
|  | 3.192 | Mg II | 2 |
| 0119-046* | 1.951 | Ly $\alpha$ | 1 |
|  | 1.964 | Mg II | 5 |
| 0123+257* | 2.358 | Ly $\alpha$ | 10 |
|  | 2.370 | [OIII] $\lambda \lambda 4959,5007$ | 8 |
| 0142-100* | 2.727 | Ly $\alpha$ | 9 |
| 0150-202* | 2.148 | Ly $\alpha$ | 2 |
|  | 2.149 | Mg II | 5 |
| 0153+744* | 2.340 | Ly $\alpha$ | 2 |
|  | 2.341 | [OIII] $\lambda 5007$ | 8 |
| 0226-038 | 2.067 | Lya | 2 |
|  | 2.073 | Mg II | 5 |
|  | 2.073 | [OIII] $\lambda \lambda 4959,5007$ | 8 |
| 0237-233 | 2.224 | Ly $\alpha$ | 9 |
|  | 2.200 | [OIII] $\lambda 5007$ | 7 |
| 0256-000 | 3.374 | Ly $\alpha$ | 1 |
| 0301-005 | 3.228 | Ly $\alpha$ | 1 |

Table 3.5: QSO Emission Line Redshifts for $J\left(\nu_{0}\right)$ Measurement ${ }^{a}$ (Continued)

| QSO | z | line ${ }^{\text {b }}$ | Ref. ${ }^{\text {c }}$ |
| :---: | :---: | :---: | :---: |
| 0302-003* | 3.286 | Ly $\alpha$ | 1 |
| 0334-204 | 3.131 | Ly $\alpha^{\prime}$ | 1 |
| 0348+061 | 2.057 | Ly $\alpha^{\prime}$ | 2 |
|  | 2.056 | Mg II | 5 |
| 0400+258 | 2.108 | Ly $\alpha$ | 2 |
| 0421+019 | 2.050 | Ly $\alpha$ | 4 |
|  | 2.056 | Mg II | 5 |
| 0424-131* | 2.165 | Ly $\alpha$ | 11 |
|  | 2.166 | Mg II | 5 |
|  | 2.163 | $\mathrm{H} \alpha$ | 12 |
| 0453-423 | 2.656 | Ly $\boldsymbol{\alpha}$ | 6 |
| 0636+680 | 3.167 | Ly $\alpha$ | 1 |
|  | 3.184 | Mg II | 2 |
|  | 3.187 | H $\beta$ | 2 |
| $0731+653$ | 3.033 | Ly $\alpha$ | 1 |
| 0747+610 | 2.491 | Ly $\boldsymbol{\alpha}$ | 2 |
| 0831+128 | 2.739 | Ly $\alpha$ | 3 |
| 0836+710* | 2.189 | Ly $\alpha$ | 2 |
|  | 2.197 | Mg II | 2 |
|  | 2.218 | [OIII] $\lambda 5007$ | 8 |
| 0837+109 | 3.323 | Ly $\alpha$ | 9 |
| $0848+155$ | 2.019 | Ly $\alpha$ | 2 |
|  | 2.014 | Mg II | 5 |
| 0848+163* | 1.925 | Ly $\alpha$ | 13 |
|  | 1.922 | Mg II | 5 |
| 0905+151 | 3.173 | Ly $\alpha$ | 3 |
| $0913+072$ | 2.785 | Ly $\alpha$ | 9 |
| 0936+368 | 2.025 | Ly $\alpha$ | 2 |
| 0938+119 | 3.192 | Ly $\alpha$ | 3 |
| $0952+335$ | 2.504 | Ly $\alpha$ | 2 |
| $0955+472$ | 2.482 | Ly $\alpha$ | 2 |
| $0956+122$ | 3.033 | Ly $\alpha$ | 2 |
|  | 3.299 | Mg II | 2 |
|  | 3.314 | H $\beta$ | 2 |
|  | 3.308 | [OIII] $\lambda 5007$ | 2 |
| $1009+299$ | 2.633 | Ly $\alpha$ | 2 |
| $1017+280$ | 1.928 | Ly $\alpha$ | 9 |

Table 3.5: QSO Emission Line Redshifts for $J\left(\nu_{0}\right)$ Measurement ${ }^{a}$ (Continued)

| QSO | z | line ${ }^{\text {b }}$ | Ref. ${ }^{\text {c }}$ |
| :---: | :---: | :---: | :---: |
| 1033+137 | 3.092 | Ly $\alpha$ | 3 |
| 1115+080* | 1.727 | Ly $\alpha$ | 14 |
| 1159+124* | 3.505 | Ly $\alpha$ | 9 |
|  | 3.508 | Mg II | 2 |
|  | 3.497 | $\mathrm{H} \beta$ | 2 |
|  | 3.497 | [OIII] $\lambda 5007$ | 2 |
| 1206+119 | 3.108 | Ly $\alpha$ | 3 |
| $1207+399$ | 2.451 | Ly $\alpha$ | 2 |
|  | 2.463 | H $\alpha$ | 2 |
| 1208+101* | 3.822 | Ly $\alpha$ | 3 |
|  | 3.833 | H $\beta$ | 2 |
|  | 3.802 | [OIII] $\lambda 5007$ | 2 |
| 1210+175* | 2.564 | Ly $\alpha$ | 2 |
| $1215+333$ | 2.606 | Ly $\alpha$ | 14 |
| 1225-017 | 2.831 | Ly $\alpha$ | 15 |
| $1225+317$ | 2.200 | Ly $\alpha$ | 6 |
|  | 2.226 | [OIII] $\lambda 5007$ | 8** |
| $1231+294$ | 2.018 | Ly $\alpha$ | 2 |
| $1247+267$ | 2.041 | Ly $\alpha$ | 9 |
| $1315+472$ | 2.590 | Ly $\alpha$ | 3 |
| 1323-107 | 2.360 | Ly $\alpha$ /C IV | 16 |
| 1329+412* | 1.934 | Ly $\alpha$ | 2 |
| 1334-005 | 2.842 | Ly $\beta$ | 3 |
| 1337+285* | 2.541 | Ly $\alpha$ | 2 |
| 1346-036 | 2.356 | Ly $\alpha$ | 2 |
|  | 2.368 | Mg II | 12 |
|  | 2.362 | [OIII] $\lambda 5007$ | 8 |
|  | 2.367 | $\mathrm{H} \alpha$ | 12 |
| 1358+115* | 2.589 | Ly $\alpha$ | 2 |
| $1400+114$ | 3.177 | Ly $\alpha$ | 3 |
| $1402+044$ | 3.208 | Ly $\alpha$ | 17 |
| $1406+492$ | 2.161 | Ly $\alpha$ | 2 |
| $1408+009$ | 2.262 | Ly $\alpha$ | 2 |
|  | 2.260 | [OIII] $\lambda 5007$ | 2 |
|  | 2.265 | $\mathrm{H} \alpha$ | 2 |
| $1410+096$ | 3.313 | Ly $\alpha$ | 3 |
| $1421+330$ | 1.903 | Ly $\alpha$ | 2 |

Table 3.5: QSO Emission Line Redshifts for $J\left(\nu_{0}\right)$ Measurement ${ }^{a}$ (Continued)

| QSO | z | line ${ }^{\text {b }}$ | Ref. ${ }^{\text {c }}$ |
| :---: | :---: | :---: | :---: |
| 1422+231* | 1.906 | Mg II | 5 |
|  | 3.624 | Ly $\alpha$ | 2 |
|  | 3.630 | H $\beta$ | 2 |
|  | 3.623 | [OIII] $\lambda 5007$ | 2 |
| $1435+638$ | 2.063 | Ly $\alpha$ | 2 |
|  | 2.061 | Mg II | 5 |
|  | 2.066 | [OIII] $\lambda \lambda 4959,5007$ | 8 |
|  | 2.065 | $\mathrm{H} \alpha$ | 2 |
| $1442+101$ | 3.560 | Ly $\alpha$ | 17 |
| $1451+123$ | 3.251 | Ly $\alpha$ | 3 |
| 1511+091* | 2.877 | C IV | 9 |
| $1512+132$ | 3.120 | Ly $\alpha$ | 3 |
| $1548+092$ | 2.759 | Ly $\alpha$ | 9 |
| 1601+182* | 3.227 | Ly $\alpha$ | 3 |
| 1602+178* | 2.989 | Ly $\alpha$ | 3 |
| 1603+383* | 2.510 | Ly $\boldsymbol{\alpha}$ | 18 |
| $1604+290$ | 1.962 | Ly $\alpha$ | 2 |
| $1607+183$ | 3.120 | Ly $\alpha$ | 17 |
| $1614+051$ | 3.216 | Ly $\alpha$ | 17 |
|  | 3.214 | [OIII] $\lambda 5007$ | 19 |
| 1623+269* | 2.526 | Ly $\alpha$ | 3 |
| $1700+642$ | 2.744 | Ly $\alpha$ | 15 |
| $1715+535$ | 1.935 | Ly $\alpha$ | 2 |
|  | 1.932 | Mg II | 5 |
| $1738+350$ | 3.239 | Ly $\alpha$ | 3 |
| 1946+770 | 3.020 | Ly $\alpha$ | 15 |
| 2126-158 | 3.280 | Ly $\alpha$ | 6 |
|  | 3.284 | Mg II | 2 |
|  | 3.298 | $\mathrm{H} \beta$ | 2 |
|  | 3.292 | [OIII] $\lambda 5007$ | 2 |
| 2134+004 | 1.941 | Ly $\alpha$ | 2 |
| $2233+131$ | 3.301 | Ly $\alpha$ | 1 |
| $2233+136$ | 3.207 | Ly $\alpha$ | 1 |
| $2251+244 *$ | 2.335 | Ly $\alpha$ | 17 |
|  | 2.359 | [OIII] $\lambda 5007$ | 8 |
| $2254+024$ | 2.089 | Ly $\alpha$ | 2 |
|  | 2.090 | Mg II | 5 |

Table 3.5: QSO Emission Line Redshifts for $J\left(\nu_{0}\right)$ Measurement ${ }^{a}$ (Continued)

| QSO | z | line $^{b}$ | Ref. $^{c}$ |
| :--- | :---: | :---: | :---: |
| $2310+385$ | 2.179 | Ly $\alpha$ | 2 |
|  | 2.181 | [OIII] $\lambda \lambda 4959,5007$ | 8 |
| $2311-036$ | 3.041 | Ly $\alpha$ | 1 |
| $2320+079$ | 2.088 | Ly $\alpha$ | 2 |
| $2329-020$ | 1.896 | Ly $\alpha$ | 2 |

Note-
Objects marked with an asterisk are excluded from the proximity effect analysis on the basis of associated absorption or gravitational lensing
${ }^{a}$ Objects with both Ly $\alpha$ and Mg II, Balmer, or [OIII] redshifts were used to construct histograms in Figure 2.3;
${ }^{6}$ Emission lines used to measure redshift
${ }^{c}$ References:
(1) Sargent et al. 1989; (2) this paper;
(3) B94; (4) Young et al. 1982a; (5) Steidel \& Sargent 1991;
(6) Sargent et al. 1980; (7) Baker et al. 1994;
(8) $\mathrm{M}^{c}$ Intosh et al. 1999a (** $1225+317$ measurement quoted as uncertain due to weak [ O III] emission and low $\mathrm{S} / \mathrm{N}$ );
(9) Sargent et al. 1988; (10) Schmidt 1968; (11) Burbidge 1970;
(12) Espey et al. List of Tables989; (13) Young et. al 1982b;
(14) Wills \& Wills 1979; (15) DB96; (16) Kunth et al. 1981;
(17) Barthel et al. 1990; (18) Hamburg Survey (unpublished);
(19) Bremer \& Johnstone 1995

Table 3.6. Ionization Rates

| $A, B, z_{c}, S$ | Ref. <br> (a) | $\chi^{2}$ <br> (b) | $\mathrm{Q}_{\chi^{2}}$ <br> (c) |
| :--- | :---: | :---: | :---: |
| $6.7 \mathrm{e}-13 \mathrm{~s}^{-1}, 0.73,2.30,1.90$ | 1 | 10.2 | 0.17 |
| $5.6 \mathrm{e}-13 \mathrm{~s}^{-1}, 0.60,2.22,1.90$ | 2 | 11.8 | 0.10 |
| $1.2 \mathrm{e}-12 \mathrm{~s}^{-1}, 0.58,2.77,2.38$ | 2 | 7.15 | 0.41 |
| (1)Haardt \& Madau (1996); (2)Fardal, Giroux, \& Shull (1998) |  |  |  |
| $\chi^{2}$ of data versus the BDO ionization model |  |  |  |
| $\chi^{2}$ probability for the BDO ionization model |  |  |  |

Table 3.7. Simulation Results

| Input $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ <br> $(\mathrm{a})$ | $\gamma, \mathcal{A}_{0}$ <br> $(\mathrm{~b})$ | $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ recovered <br> $(\mathrm{c})$ | $\chi^{2}$ <br> $(\mathrm{~d})$ | $\mathrm{Q}_{\chi^{2}}$ <br> $(\mathrm{e})$ |
| :---: | :---: | :---: | :---: | :---: |
| -23.0 | $1.5722,11.043$ | $-22.75_{-0.19}^{+0.28}$ | 11.2 | 0.12 |
| -22.0 | $1.6869,8.8367$ | $-21.80_{-0.28}^{+0.40}$ | 11.3 | 0.12 |
| -21.3 | $2.6267,2.6960$ | $-21.00_{-0.60}^{+0.28}$ | 2.68 | 0.91 |
| -20.0 | $2.2511,3.8084$ | $-19.50_{-0.84}^{+1.86}$ | 3.90 | 0.79 |
| -19.0 | $2.0302,5.2704$ | $-18.50_{-1.56}^{+0.66}$ | 5.28 | 0.62 |

${ }^{\text {a }}$ value of $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ used for modifying absorber column densities according to Equations 3.7 and 4.4
${ }^{b}$ Equ. 3.1 parameters $\gamma$ and $\mathcal{A}_{0}$
from maximum likelihood fit to data
${ }^{c}$ value of $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ from simulated
spectra using the standard BDO technique
${ }^{d} \chi^{2}$ of data versus the BDO ionization model
${ }^{e} \chi^{2}$ probability for the BDO ionization model

Table 3.8. Literature Proximity Effect Measurements of $J\left(\nu_{0}\right)$

| $\log \left[\left(J\left(\nu_{0}\right)\right]\right.$ | $z$ | $\mathcal{N}_{Q S O s}$ | Ref. $^{a}$ |
| :--- | :---: | :---: | :---: |
| $-23.2_{-0.6}^{+0.8}$ | $0.16-0.99$ | 13 | 1 |
| $-20.5_{-1.3}^{+0.6}$ | $1.8-2.3$ | 3 | $2^{b}$ |
| $-21.1 \pm 0.6$ | 2.0 | 1 | 2 |
| -21.15 | 3.2 | 1 | 3 |
| -21.3 | 3.6 | 1 | 4 |
| $-21.0 \pm 0.5$ | $1.7-3.8$ | 38 | 5 |
| $-21.0 \pm 0.5$ | $1.7-3.8$ | 19 | 6 |
| -20.5 | $1.6-4.1$ | 49 | 7 |
| $-21.3_{-0.09}^{+0.08}$ | $1.7-4.1$ | 10 | 8 |
| $-21.1_{-0.27}^{+0.15}$ | $1.7-4.1$ | 74 | 9 |
| $-21.0_{-0.15}^{+0.17}$ | $2.0-4.5$ | 11 | 10 |
| $-22.0--21.5$ | 4.5 | 1 | 11 |
| a (1) Kulkarni \& Fall 1993; |  |  |  |
| (2) Fernández-Soto et al. $1995 ;$ |  |  |  |
| (3) Giallongo et al. 1993; |  |  |  |
| (4) Cristiani et al. 1995; |  |  |  |
| (5) BDO: (6) LWT; (7) B94; |  |  |  |
| (8) Giallongo et al. 1996; |  |  |  |
| (9) this paper; |  |  |  |
| (10) Cooke et al. 1997; |  |  |  |
| (11) Williger et al. (1994) |  |  |  |
| measured from the proximity effect |  |  |  |
| due to a foreground QSO; not able |  |  |  |
| to set an upper limit |  |  |  |



Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs: Dashed line indicates the power law continuum fit; dotted line indicates the $1 \sigma$ errors: (a) $0006+202$; (b) $0027+018$; (c) 0037-018: (d) $0049+007$; (e) $0123+257$; (f) $0153+744$; (g) $0348+061$; (h) 1323-107; (i) $1346-036$; (j) $1422+231$; (k) $2134+004$; (l) $2251+244$; (m) $2254+022$


Figure 3.1. Spectrophotometry of $\mathrm{z} \approx 2$ QSOs (Continued)


Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued)


Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued)


Figure 3.1. Spectrophotometry of $z \approx 2$ QSOs (Continued)


Figure 3.2. Infrared QSO spectra, line identifications as listed in Table 3.5 are marked: (a) 0000-263; (b) 0014+813 (J); (c) 0014+813 (K) (d) 0114-089; (e) $0636+680(\mathrm{~J}):(\mathrm{f}) 0636+680(\mathrm{~K}) ;(\mathrm{g}) 0836+710$, flux units are $10^{26} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2}$ $\mathrm{Hz}^{-1} \mathrm{sr}^{-1}$; (h) $0956+122$ (J); (i) $0956+122$ (K); (j) $1159+124$ (J); (k) $1159+124$ (K); (l) $1207+399$; (m) $1208+101$; (n) $1408+009$ (H); (o) $1408+009$ (K); (p) $1422+231$; (q) $1435+638$; (r) $2126-158(\mathrm{~J})$; (s) $2126-158(\mathrm{~K})$


Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued)


Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued)


Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued)


Figure 3.2. Infrared spectra of $z \approx 2$ QSOs (Continued)


Figure 3.3. Lyman limit luminosity versus redshift for the proximity effect dataset; squares- QSOs from which low redshift line sample was taken; crosses- QSOs from which high redshift line sample was taken; the line marks the boundary between low and high luminosity QSOs


Figure 3.4. Relative deficit of lines with respect to the number predicted by Equ. 3.1 versus distance from the QSO for lines with rest equivalent width greater than $0.32 \AA$ (a) total sample; (b) low luminosity QSOs; (c) high luminosity QSOs


Figure 3.5. $\chi^{2}$ of binned data with respect to the ionization model with a constant $J\left(\nu_{0}\right)$ versus $\log \left[J\left(\nu_{0}\right)\right]$ : (a) DB96 sample; (b) all lines, Ly $\alpha$ QSO redshifts; (c) all lines, using narrow line redshifts where available, Ly $\alpha$ redshifts otherwise; (d) all lines, narrow line redshifts where available, Ly $\alpha$ redshifts $+400 \mathrm{~km} \mathrm{~s}^{-1}$ otherwise; (e) high $z$ lines, QSO redshifts as in case (d); (f) low $z$ lines, QSO redshifts as in case (d); (g) high luminosity QSOs, QSO redshifts as in case (d); (h) low luminosity QSOs, QSO redshifts as in case (d); (i) weak lines only: $0.16 \AA<W<0.32 \AA$, QSO redshifts as in case (d); (j) lines from QSOs with damped Ly $\alpha$ systems only, QSO redshifts as in case (d)


Figure 3.6. Number distribution per coevolving redshift coordinate for the best fit values of $J\left(\nu_{0}\right)$ (BDO method); (a-j) same as Fig. 3.5


Figure 3.7. Likelihood function versus $\log \left[J\left(\nu_{0}\right)\right]:$ (a-f) same as Fig. 3.5


Figure 3.8. Number distribution per coevolving redshift coordinate for the best fit values of $J\left(\nu_{0}\right)$ (KF method); (a-f) same as Fig. 3.5


Figure 3.9. Histograms of redshift differences with respect to the [OIII] $\lambda 5007$ line (a) Ly $\alpha$; (b) Mg II; (c) Balmer lines ; dotted lines- data of Laor et al. (1995), dashed lines- data of Nishihara et al. (1997)


Figure 3.10. Sample simulation spectra plotted with data, flux scale is arbitrary. (a) $0014+813:$ (i)data, (ii) input $\log \left[J\left(\nu_{0}\right)\right]=-23.0$, (iii) input $\log \left[J\left(\nu_{0}\right)\right]=-22$, (iv)input $\log \left[J\left(\nu_{0}\right)\right]=-21.3$, (v)input $\log \left[J\left(\nu_{0}\right)\right]=-20.0$, (vi)input $\log \left[J\left(\nu_{0}\right)\right]=-19.0$; (b) $1700+643$ : (i)-(vi) same as in (a)


Figure 3.10. Sample simulation spectra (Continued)


Figure 3.11. Number distribution per coevolving redshift coordinate for the best fit values of $J\left(\nu_{0}\right)$ listed in Table 2.4; solid lines- simulation, dotted lines- data, scaled by the relevant value of $\mathcal{A}_{0}$ in Table 2.4: (a)input $\log \left[J\left(\nu_{0}\right)\right]=-23.0$; (b)input $\log \left[J\left(\nu_{0}\right)\right]=-$ 22; (c)input $\log \left[J\left(\nu_{0}\right)\right]=-21.3$; (d)input $\log \left[J\left(\nu_{0}\right)\right]=-20.0$; (e)input $\log \left[J\left(\nu_{0}\right)\right]=-19.0$


Figure 3.12. Curve of growth effects: ratio of post- to pre- proximity effect rest equivalent width for all lines versus pre- proximity effect rest equivalent width; solid line represents the detection threshold $W_{P E}=0.32 A$; (a)-(e) as in Fig. 3.11


Figure 3.13. Measurements of $\log \left[J\left(\nu_{0}\right)\right]$ versus redshift: points and error bars are taken from Table 3.8. The upper limit set by Bunker et al. (1998) at $\mathrm{z} \sim 3$ is included. Measurements over extended redshift ranges and the errors in those measurements are indicated by boxes. The solid curves are derived from the Haardt \& Madau (1996) model for the HI photoionization rate as a function of redshift for QSO spectral indicies of 0 (lower curve) and 2 (upper curve). Overall, measurements at $z=2-3$ agree well with one another and with the predictions of the Haardt \& Madau (1996) model.


Figure 3.14. Power law fits to $\log \left[J\left(\nu_{0}\right)\right]$ as a function of redshift: $J\left(\nu_{0}, z\right)=$ $J\left(\nu_{0}, 0\right)(1+z)^{j}$. The dashed lines indicate the two lowest $\chi^{2}$ fits to the data: $\left(j, \log \left[J\left(\nu_{0}, 0\right)\right]\right)=(5.12,-23.97)$ and (-4.16,-18.76). The solid curves are the Haardt \& Madau (1996) models as shown in Figure 3.13. The Haardt \& Madau (1996) models are turning over at the redshift of the data, precluding a strong constraint on the parameters $j$ and $J\left(\nu_{0}, 0\right)$; but the lowest $\chi^{2}$ fit extends to low redshift to match the Kulkarni \& Fall (1993) measurement shown by the box, while the next lowest $\chi^{2}$ fit extends to high redshift to match the Williger et al. (1994) measurement, the point at $z=4.5$.

## Chapter 4

## HST/FOS Data and the Ultraviolet Background at $Z<1.7$

### 4.1 Data Sample

The reduction of the FOS data is described in Paper III. Table 4.1 lists the objects used in the proximity effect analysis along with the object's redshift and classification in the NASA Extragalactic Database.

For the reasons outlined in Scott et al. (2000b, hereafter Paper II) we have removed from the full FOS sample of Paper III the spectra of quasars known to be lensed, as well as those that show damped Ly- $\alpha$ absorption, associated absorption, or broad intrinsic absorption. For our primary proximity effect sample, we also remove objects classified as blazars (BL Lacs and optically violent variables) on the grounds that their continua are highly variable. However, we also perform the proximity effect analysis with associated absorbers, damped Ly- $\alpha$ absorbers, and blazars included in order to determine if they affect the results obtained.

As discussed in Paper III, objects observed only in the period before the COSTAR upgrade to the HST optics and with the A-1 FOS aperture are particularly subject to irregular line spread functions. We have omitted those data from this analysis as well. The distributions in redshift of the QSOs and absorption lines used in this paper are shown in Figure 4.1.

### 4.2 Systemic Redshifts

QSO redshifts based on the Ly- $\alpha$ emission line have been shown to be blueshifted from the systemic redshift based on narrow emission lines by up to $\sim 200 \mathrm{~km} \mathrm{~s}^{-1}$. Generally, the forbidden OIII doublet at $4959,5007 \AA$ is taken to be the most reliable
indicator of the QSO systemic redshift; though other lines such as Mg II $\lambda \lambda 2796,2803$ and Balmer lines have been shown to trace the systemic redshift as well, with some spread. (Zheng \& Sulentic 1990, Tytler \& Fan 1992, Laor et al. 1994,1995, Corbin \& Boroson 1996) However, the results of Nishihara et al. (1997), M'Intosh et al. (1999), and Paper II indicate that in fact $\mathrm{H} \beta$ may not reflect the systemic redshift of high redshift QSOs.

### 4.2.1 Observations

Spectra of the emission lines $\mathrm{H} \beta$, [OIII] $\lambda 5007$, or Mg II were obtained for several objects in our total proximity effect sample. The observations were carried out on the nights of 19 December 1995, 14 January 1996, 20 and 21 April 1996, 12 and 13 December 1996, and 2 February 1997. These observations are summarized in Table 4.2.

The 19 December 1995 and 13 December 1996 observations were made using the 1.5 meter Tillinghast telescope at the Fred Lawrence Whipple Observatory using the FAST spectrograph (Fabricant et al. 1998) and a thinned Loral 512x2688 CCD chip (gain $=1.06$, read noise $=7.9 \mathrm{e}^{-}$) binned by a factor of 4 in the cross-dispersion direction. Observations were made using a 300 lines $\mathrm{mm}^{-1}$ grating blazed at $4750 \AA$ and a $3^{\prime \prime}$ slit. These spectra cover a wavelength range of $3660-7540 \mathrm{~A}$. This is listed as set-up (1) in Table 4.2.

The January, April, and December 10 and 12, 1996 observations were made using the Steward Observatory Bok 90 inch telescope using the Boller and Chivens Spectrograph with a $600 \mathrm{l} \mathrm{mm}^{-1}$ grating blazed at $6681 \AA$ in the first order, a $1.5^{\prime \prime}$ slit, and a $1200 \times 800 \mathrm{CCD}$ array with a gain of $2.2 \mathrm{e}^{-} \mathrm{ADU}^{-1}$ and a read noise of 7.7 $\mathrm{e}^{-}$, binned 1xl. For the January 1996 observations, the data were obtained with one of two grating tilts, one resulting in wavelength coverages of $3600-5825 \AA$ and 6870-9140 $\AA$. For the April 1996 data, the wavelength ranges were $4140-6370 \AA$ and

5280-7550 $\AA$. Two grating tilts were also used for the December 1996 data, giving wavelength coverages of $4500-6700 \AA$ and $5610-7860 \AA$.

The spectrum of one object, 0827+2421, was obtained on 15 February 1997 at the Multiple Mirror Telescope with the Blue Channel Spectrograph, a 2 " slit, the 3 K x 1 KCCD array, and the $800 \mathrm{I} \mathrm{mm}^{-1}$ grating blazed at $4050 \AA$ with spectral coverage of 4365-6665 $\AA$.

The spectra are shown in Figure 4.2 and the lines used for redshift measurements are labeled.

### 4.2.2 Measurements

Taking a simple cursor measurement of each line centroid, we find a mean [OIII]Balmer line $\Delta \mathrm{v}$ of $-30 \pm 1010 \mathrm{~km} \mathrm{~s}^{-1}$ for 31 objects and a mean [OIII]-Mg II $\Delta \mathrm{v}$ of $58 \pm 576 \mathrm{~km} \mathrm{~s}^{-1}$ for 31 objects. The mean blueshift of the Ly- $\alpha$ emission line with respect to [OIII] is $289 \pm 727 \mathrm{~km} \mathrm{~s}^{-1}$ based on 51 measurements. The redshifts measured for each object in our sample are shown in Table 4.1; and the results are shown in Figure 4.3. Gaussian fits to the lines give similar results.

We therefore treat both Balmer lines and Mg II in addition to [OIII] as good systemic redshift indicators for these low redshift objects. In the case of a QSO for which we have only a Ly- $\alpha$ emission line measurement of the redshift, we add 300 $\mathrm{km} \mathrm{s}^{-1}$ to this value to estimate its systemic redshift.

### 4.3 Lyman Limit Fluxes

Our method for estimating Lyman limit fluxes for each QSO is the same as that described in Paper II. For objects with spectral coverage between the Ly- $\alpha$ and CIV emission lines, we extrapolate the flux from $1450 \AA$ in the quasar's rest frame to $912 \AA$ using $f_{\nu} \sim \nu^{-\alpha}$ and a spectral index $\alpha$ measured primarily from the spectral region between the Ly- $\alpha$ and C IV emission lines. Figure 4.4 shows the FOS spectra for
which these fits were made along with the power law fits themselves. In some cases, $\alpha$ is poorly constrained from these fits, especially if there was little spectral coverage redward of $\mathrm{Ly}-\alpha$ emission in the data. If another measurement of the spectral index was available in the literature for these objects, we used it; otherwise, we used our measurement.

Table 4.3 lists the Lyman limit flux for each object in this proximity effect sample and either a) the flux at $1450 \AA$, or some other appropriate wavelength free of emission features, measured from the FOS data, or b) a directly measured Lyman limit flux and the reference. If available from the extracted archive data, red spectra and the fits to them are presented for objects which were observed only with pre-COSTAR FOS and A-1 aperture, though these data were not subsequently used for any Ly- $\alpha$ forest studies. See Table 4 of Paper III.

In Figure 4.5, we show QSO Lyman limit luminosities versus emission redshift for this HST/FOS sample combined with the high redshift objects presented in Papers I and II. Only at the lowest redshifts is there any trend of luminosity with redshift.

### 4.4 Analysis

The distribution of $\mathrm{Ly}-\alpha$ lines in redshift and equivalent width is given by:

$$
\begin{equation*}
\frac{\partial^{2} \mathcal{N}}{\partial z \partial W}=\frac{A_{0}}{W^{*}}(1+z)^{\gamma} \exp \left(-\frac{W}{W_{*}}\right) \tag{4.1}
\end{equation*}
$$

The distribution in redshift and HI column density, N , is:

$$
\begin{equation*}
\frac{\partial^{2} \mathcal{N}}{\partial z \partial N}=A N^{-\beta}(1+z)^{\gamma} \tag{4.2}
\end{equation*}
$$

The parameter $\gamma$ is the redshift distribution parameter. The quantities $W^{*}$ in Equ. 4.1 and $\beta$ in Equ. 4.2 are the line rest equivalenth width and column density distribution parameters, respectively. The quantities $A_{0}$ and $A$ are normalizations.

The BDO method for measuring $J\left(\nu_{0}\right)$ consists of binning all lines in the sample in the parameter $\omega(z)$, the ratio of QSO to background Lyman limit flux density at
the physical location of the absorber: $F^{Q}\left(\nu_{0}\right) /\left(4 \pi J\left(\nu_{0}\right)\right)$ for various values of $J\left(\nu_{0}\right)$. The value of $J\left(\nu_{0}\right)$ that results in the lowest $\chi^{2}$ between the binned data and the ionization model,

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=\mathcal{A}_{0}(1+z)^{\gamma}[1+\omega(z)]^{-(\beta-1)} \tag{4.3}
\end{equation*}
$$

is considered to be the optimal value. This ionization model follows from the assumption that the column densities of lines are modified by the presence of the QSO according to

$$
\begin{equation*}
N \propto N_{0}(1+\omega(z))^{-1} \tag{4.4}
\end{equation*}
$$

where $N_{0}$ is the column density a given line would have in the absence of the QSO. The $1 \sigma$ errors are found from $\Delta \chi^{2}=8.18$ for 7 degrees of freedom (Press et al. 1992).

The value of $\omega(z)$ for each line in a given sample depends not only upon the value of $J\left(\nu_{0}\right)$ assumed, but also on the cosmological model, as

$$
\begin{equation*}
F^{Q}\left(\nu_{0}\right)=\frac{L\left(\nu_{0}\right)}{4 \pi r_{L}^{2}(z)} \tag{4.5}
\end{equation*}
$$

and

$$
\begin{equation*}
L\left(\nu_{0}\right)=4 \pi d_{L}^{2}(z) \frac{f\left(\nu_{0}\right)}{\left(1+z_{e m}\right)}, \tag{4.6}
\end{equation*}
$$

where $r_{L}(z)$ is the luminosity distance of an individual absorber from the QSO and $d_{L}(z)$ luminosity distance to the QSO from the observer. The luminosity distance between two objects at different redshifts can be calculated analytically for cosmological models in which $\Omega_{\Lambda}=0$. We return to this point in Section 4.6.2 below.

If the proximity effect is indeed caused by enhanced ionization of the IGM in the vicinity of QSOs, one may expect to observe a larger deficit of lines relative to the Ly- $\alpha$ forest near high luminosity QSOs than near low luminosity QSOs. In Figure 4.6(a), we plot the fractional deficit of lines with respect to the number predicted by Equ. 4.1 versus distance from the QSO for this HST/FOS sample combined with the high redshift objects observed with the Multiple Mirror Telescope (MMT) presented in Papers I and II. We divide our QSO sample into high and low luminosity
objects at the median Lyman limit luminosity of the combined MMT and HST/FOS sample, $\log \left(\mathrm{L}_{912} \AA\right) \sim 31$. High luminosity objects show a marginally more pronounced proximity effect than low luminosity objects: $4.9 \sigma$ for QSOs with $\log \left(\mathrm{L}_{912} \mathrm{~A}\right)>31$ versus $3.2 \sigma$ for QSOs with $\log \left(\mathrm{L}_{912} \mathrm{~A}\right)<31$. In panel (b), we plot the line deficit within $2 \mathrm{~h}_{75}^{-1} \mathrm{Mpc}$ as a function of $\log \left(\mathrm{L}_{912} \AA\right.$ ). The lack of a significant difference in the line deficit between high and low luminosity QSOs may indicate the presence of clustering, if absorption features cluster more strongly around more luminous QSOs with deeper potential wells. We will address the issue of clustering further below.

The BDO method of measuring the background can result in poor statistics at low redshift due to the low line density in the low redshift Ly- $\alpha$ forest. We will quote results from this method, but we will generally use the maximum likelihood method for measuring $J\left(\nu_{0}\right)$ as presented by KF93, which consists of constructing a likelihood function of the form

$$
\begin{equation*}
L=\prod_{a} f\left(N_{a}, z_{a}\right) \prod_{q} \exp \left[-\int_{z_{\min }^{q}}^{z_{\max }^{q}} d z \int_{N_{\min }^{q}}^{\infty} f(N, z) d N\right] \tag{4.7}
\end{equation*}
$$

where

$$
\begin{equation*}
f(N, z)=A N^{-\beta}(1+z)^{\gamma}[1+\omega(z)]^{-(\beta-1)} \tag{4.8}
\end{equation*}
$$

and the indicies $a$ and $q$ denote sample absorption lines and quasars, respectively. Using the values of $\gamma$ and $A_{0}$ from a separate maximum likelihood analysis on the Ly$\alpha$ forest excluding regions of the spectra affected by the proximity effect (Dobrzycki et al. 2001, hereafter Paper IV), and a value of $\beta$ from studies with high resolution data, eg. $\beta=1.46$ from Hu et al. (1995), the search for the best-fit value of $J\left(\nu_{0}\right)$ consists of finding the value that maximizes this function, fixing the other parameters.

If the line density is low throughout a single Ly- $\alpha$ forest spectrum, it becomes difficult to distinguish any proximity effect, even in a large sample of spectra. The absence of a proximity effect in this model formally translates into the limit $J\left(\nu_{0}\right) \rightarrow$ $\infty$ because in this scenario, the QSO has no additional effect on its surroundings and
therefore generates no relative line underdensity. The errors quoted in the values of $\log \left[J\left(\nu_{0}\right)\right]$ are found from the fact that in solving for $\log \left[J\left(\nu_{0}\right)\right]$ alone, the logarithm of the likelihood function, $-2 \ln \left(L / L_{\max }\right)$, is distributed as $\chi^{2}$ with one degree of freedom. In the case of an ill-defined solution, the likelihood function is very broad and the formal error approaches infinity. If a proximity effect is weak but not absent in the data, a maximum likelihood solution is sometimes possible, but with no welldefined $1 \sigma$ upper limit on $\log \left[J\left(\nu_{0}\right)\right]$. In other words, if an upper limit of infinity is quoted, the data cannot rule out the nonexistence of a proximity effect to within $1 \sigma$ confidence.

Using a constant equivalent width threshold results in the loss of a large amount of spectral information. In the case of a large equivalent width threshold, of course, many weak lines are discarded; and in the case of a small threshold, regions of spectra where the signal-to-noise ratio ( $\mathrm{S} / \mathrm{N}$ ) does not permit the detection of lines all the way down to the specified threshold are lost and only the highest $\mathrm{S} / \mathrm{N}$ spectral regions are used. The technique of measuring the statistics $\gamma$ and $W^{*}$ has been expanded to allow for a threshold that varies with $\mathrm{S} / \mathrm{N}$ across each QSO spectrum (Bahcall et al. 1993,1996, Weymann et al. 1998, Scott et al. 2000a). We will use this variable threshold information to measure $J\left(\nu_{0}\right)$ as well.

### 4.5 Results

The results of this analysis are given in Table 3.4.
Before we begin the discussion of the results, some words about the normalization values listed in Table 3.4 are in order. In the BDO method for measuring $J\left(\nu_{0}\right)$, lines are binned in $\omega(z)$ and compared to the ionization model given by Equ. 4.3, for an assumed value of $\beta$. In this case, the normalization listed in Table 3.4 is the parameter in Equ. 4.1, found from the number of lines in the sample and the maximum likelihood
value of $\gamma$ :

$$
\begin{equation*}
\mathcal{A}_{0}=A_{0} \exp \left(-\frac{W_{\lim }}{W_{*}}\right)=\mathcal{N}\left(\sum_{q} \int_{z_{\min }^{q}}^{z_{\max }^{q}} d z(1+z)^{\gamma}\right)^{-1}, \tag{4.9}
\end{equation*}
$$

where $\mathcal{N}$ is the total number of lines observed with rest equivalent width greater than $W_{\text {lim }}$, the limiting equivalent width of the line sample. For the maximum likelihood solutions for $J\left(\nu_{0}\right)$, we convert line equivalent widths to column densities using the Ly- $\alpha$ curve of growth and an assumed value of $b$, the characteristic Doppler parameter of the lines. As we will demonstrate, different values of $\beta$ and $b$ have only a small effect on the value of $J\left(\nu_{0}\right)$ found. The normalization is given by

$$
\begin{equation*}
A=\mathcal{N}\left(\sum_{q} \int_{z_{\min }^{q}}^{z_{\max }^{q}} d z \int_{N_{\min }^{q}(z)}^{\infty} d N N^{-\beta}(1+z)^{\gamma}\right)^{-1} \tag{4.10}
\end{equation*}
$$

where $N_{\min }^{q}(z)$ is the limiting column density across each QSO spectrum corresponding to a limiting equivalent width. This quantity can be held constant, as in the BDO method, or it can be allowed to vary across each QSO spectrum. In both of these formulations for the normalization, a proximity region around the QSO is neglected and that proximity region is either defined by a velocity cut, eg. $z_{\mathrm{em}}-3000 \mathrm{~km} \mathrm{~s}^{-1}$, or by a cut in $\omega(z)$, eg. $\omega(z)=0.2$.

We also use the standard BDO method to find $\log \left[J\left(\nu_{0}\right)\right]=-22.04_{-1.11}^{+0.43}$ and $-22.06_{-0.62}^{+0.05}$ for equivalent width thresholds of 0.32 and $0.24 \AA$ respectively. Figures $4.7(\mathrm{a})$ and ( d ) illustrate the $\chi^{2}$ of the binned data compared to the BDO ionization model as a function of assumed $J\left(\nu_{0}\right)$ for these two thresholds. The BDO ionization model is expressed in terms of the number of lines per coevolving coordinate:

$$
\begin{equation*}
\frac{d N}{d X_{\gamma}}=\mathcal{A}_{0}(1+\omega)^{-(\beta-1)} \tag{4.11}
\end{equation*}
$$

where $X_{\gamma}=\int(1+z)^{\gamma} d z$. This $\chi^{2}$ curve is very broad, which is reflected in the large error bars and indicates the difficulty in isolating the optimal mean intensity of a weak background using this technique. Figures 4.8(a) and (d) show the binned data
and the ionization model for the values of $J\left(\nu_{0}\right)$ listed above, those that give the lowest $\chi^{2}$ between the binned data and the model, ie. the minima of the curves in Figures 4.7(a) and (d).

We executed the maximum likelihood search for $J\left(\nu_{0}\right)$, using two different fixed equivalent width thresholds, $0.24 \AA$ and $0.32 \AA$ as well as for the case of a variable threshold across all the spectra. The uncertainty in $\gamma$ does not translate directly into a large uncertainty in $J\left(\nu_{0}\right)$. Changing the value of $\gamma$ alters the maximum likelihood normalization, $A$, according to Equ. 4.10. From the sample of lines with rest equivalent widths greater than $0.32 \AA$ we find $\log \left[J\left(\nu_{0}\right)\right]=-22.11_{-0.40}^{+0.51}$ for $\gamma=$ $0.82 \pm 0.29$. Varying $\gamma$ by $\pm 1 \sigma$ gives $\log \left[J\left(\nu_{0}\right)\right]=-22.21$ and -22.00 with similar uncertainties.

The data used here are not of sufficient resolution to fit Voigt profiles to the absorption features and derive HI column densities and Dopper parameters. We therefore choose to fix the values of $\beta$ and $b$ to those found from work on high resolution data, rather than allow them to freely vary in our analysis. For the $0.32 \AA$ fixed equivalent width threshold, we tested several pairs of values of $(\beta, b)$ where $b$ is in $\mathrm{km} \mathrm{s}^{-1}$ : $(1.46,35)$ and $(1.46,25)$ where the value of $\beta$ is taken from Hu et al. (1995); as well as $(1.45,25)$ and $(1.70,30)$ found from low redshift Ly- $\alpha$ forest spectra taken with the Goddard High Resolution Spectrograph (GHRS) on HST by Penton et al. (2000a,b). In addition, Davé \& Tripp (2001) have found some evidence for $\beta$ increasing to 2.04 at $z<0.3$ from high resolution echelle data from the Space Telescope Imaging Spectrograph aboard the HST. We test this value as well. The likelihood functions for the maximum likelihood solutions listed in rows 2-6, 8-12, 14, and 18 of Table 3.4 are shown in Figure 4.9. The binned data and ionization models are plotted in Figure 4.10. The values of $J\left(\nu_{0}\right)$ derived for these various pairs of values of $\beta$ and $b$ are not significantly different from one another, though the results in Table 3.4 indicate that varying $\beta$ has a larger impact on the inferred $J\left(\nu_{0}\right)$ than does varying $b$. The solution for $\beta=2.04$ differs from the $\beta=1.46$ solution by $\sim 1 \sigma$.

In the analysis that follows, we adopt the values 1.46 and $35 \mathrm{~km} \mathrm{~s}^{-1}$.
The models of Haardt \& Madau (1996) predict that the UV background arising from QSOs drops by over an order of magnitude from $z=2.5$ to $z=0$. We therefore divide the sample into low and high redshift subsamples at $z=1$ and use both the BDO method and the maximum likelihood method for finding $J\left(\nu_{0}\right)$. These results, also listed in Table 3.4, confirm some evolution in $J\left(\nu_{0}\right)$, though not at a high level of significance. For the BDO solutions, we find $\log \left[J\left(\nu_{0}\right)\right]$ at $z<1$ is equal to $-22.87_{-0.82}^{+1.19}$ and $\log \left[J\left(\nu_{0}\right)\right]$ at $z>1$ is equal to $-22.02_{-1.33}^{+0.005}$. The restrictive $1 \sigma$ upper limit for $\log \left[J\left(\nu_{0}\right)\right]$ at $z>1$ arises from the steeply rising $\chi^{2}$ as a function of $\log \left[J\left(\nu_{0}\right)\right]$ shown in Figure 4.7. This, in turn arises from the single line in the highest $\log (\omega)$ bin moving to the next bin for larger values of $J\left(\nu_{0}\right)$, resulting in a drastic change in the $\chi^{2}$ with respect to the photoionization model. We do not consider this to be a reliable indicator of the uncertainty in $J\left(\nu_{0}\right)$ at $z>1$. The maximum likelihood technique gives more robust estimates of the uncertainties. From this analysis, we find $\log \left[J\left(\nu_{0}\right)\right]$ at $z<1$ is found to be $-22.18_{-0.61}^{+0.90}$, while at $z>1$ it is $-21.98_{-0.54}^{+0.76}$. These results are shown in Figures 4.11(a) and 4.16.

Including associated absorbers, damped $\mathrm{Ly}-\alpha$ absorbers, or blazars in the proximity effect analysis appears to have little effect on the results. One might expect associated absorbers to reduce the magnitude of the observed proximity effect and hence cause $J\left(\nu_{0}\right)$ to be overestimated. The value found including the 45 associated absorbers in our sample is indeed larger, $\log \left[J\left(\nu_{0}\right)\right]=-21.74_{-0.39}^{+0.55}$, versus $\log \left[J\left(\nu_{0}\right)\right]=-22.11_{-0.40}^{+0.51}$, but not significantly so. Likewise, if the intervening dust extinction in damped Ly- $\alpha$ absorbers is significant, including these objects in our analysis could cause us to overestimate the magnitude of the proximity effect and hence underestimate $J\left(\nu_{0}\right)$. However, the inclusion of these 7 objects only negligibly reduces the value of $J\left(\nu_{0}\right)$ derived. QSO variability on timescales less than $\sim 10^{5}$ years would be expected to smooth out the proximity effect distribution (BDO). However, the inclusion of 6 blazars in the sample, all at $z<1$, resulted in no discernible
change in $J\left(\nu_{0}\right)$. The sample used in the analysis of HI ionization rates discussed below includes all of these objects.

For each solution, we calculate the $\chi^{2}$ with respect to the ionization model expressed by Equ. 4.3, and the probability that the observed $\chi^{2}$ will exceed the value listed by chance for a correct model, $\mathrm{Q}_{\chi^{2}}$ (Press et al. 1992). We also execute a Kolmogorov-Smirnov (KS) test for each solution. The KS test provides a measure of how well the assumed parent distribution of lines with respect to redshift, given by Equ. 4.8, reflects the true redshift distribution of lines (cf. Murdoch et al. 1986, Press et al. 1992). The KS probability, $\mathrm{Q}_{\mathrm{KS}}$, indicates the probability that a value of the KS statistic larger than the one calculated could have occurred by chance if the assumed parent is correct. The KS probability associated with each solution for $J\left(\nu_{0}\right)$ is listed in column 10 of Table 3.4.

### 4.5.1 Simulations

We tested our maximum likelihood methods, including our treatment of the variable equivalent width thresholds by running our analysis on a simulated data set. Each of the 151 spectra in this simulated data set had a redshift equal to that of an object in our data set. All objects including those showing associated absorption, damped Ly- $\alpha$ absorption, or blazar activity are included in this simulated set. Each spectrum is created using a Monte Carlo technique by which lines are placed in redshift and column density space according to Equ. 4.2. A background of known mean intensity modifies the column densities of the lines according to the BDO formulation given by Equ. 4.4. The same analysis done on the data, consisting of the line-finding algorithm and the maximum likelihood searches for $\gamma$ and $J\left(\nu_{0}\right)$, is then used on the simulated spectra in order to recover the input $J\left(\nu_{0}\right)$. Three different values of $\log \left[J\left(\nu_{0}\right)\right]$ are input, $-21,-22$, and -23 , and the results are listed in Table 4.5. In order to understand the possible range of recovered $\log \left[J\left(\nu_{0}\right)\right]$, we repeated the input
$\log \left[J\left(\nu_{0}\right)\right]=-22$ simulation in the constant threshold case nine additional times, resulting in $\overline{J\left(\nu_{0}\right)}=2.91 \pm 1.67 \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$. In addition, since we observe the background to evolve with redshift from $z=1.7$ to $z=0$, we implement a model in which $J\left(\nu_{0}\right)$ varies as a power law in $(1+z)$ over the redshift range of the data. This relationship is defined by the best fit to a power law variation of $J\left(\nu_{0}\right)$ with redshift: $\log \left[J\left(\nu_{0}\right)\right]=0.017 \log (1+z)-21.87$. We recover this using both the constant threshold and the variable threshold analyses, at all redshifts and at $z<1$ and $z>1$ separately. The results of this exercise are shown in Table 4.5 and in Figure 4.12.

These simulation results indicate that both the constant and variable threshold analyses can overestimate the background by up to a factor of 3-5, though the uncertainties for the variable threshold solutions are consistently lower, as a factor of $\sim 2$ more lines are used in these solutions. We separated the first of the input $\log \left[J\left(\nu_{0}\right)\right]=-22$ simulated data samples into high and low redshift subsamples at $z=1$, in order to determine if the change in $J\left(\nu_{0}\right)$ as a function of redshift could be falsely introduced in a case there the input background is constant with redshift. For both the constant and variable threshold treatments, this is not the case. The value found for the low redshift subsample is actually larger than the value found for the high redshift subsample in both treatments.

In the case of the varying input $\log \left[J\left(\nu_{0}\right)\right]$, the values recovered for the high redshift subsample and for the entire redshift range of the data are overestimates. The slope of the linear relationship between $\log \left[J\left(\nu_{0}\right)\right]$ and $\log (1+z)$ is quite small, 0.017 , resulting in a variable input $\log \left[J\left(\nu_{0}\right)\right]$ that is actually nearly constant with redshift. The solution for $z<1$ matches the input well for both the constant and variable threshold cases. At $z>1$, the variable threshold solution overestimates the input by a larger factor, $\sim 3$, or $1.6 \sigma$, than does the constant threshold solution, $\sim 2$, or less than $1 \sigma$.

In Paper II, we argued that curve-of-growth effects are likely to come into play
in the proximity effect analysis and to play a larger role for cases in which $J\left(\nu_{0}\right)$ is large and the proximity effect signature is small. Here we find that the input $J\left(\nu_{0}\right)$ is recovered most effectively by the constant and variable threshold cases for the largest input value of $\log \left[J\left(\nu_{0}\right)\right],-21$. However, nearly every case tested with these simulations results in a value of $J\left(\nu_{0}\right)$ larger than the input value, especially when a variable equivalent width threshold is used. The only case where the difference is significant is the input $\log \left[J\left(\nu_{0}\right)\right]=-23$, variable threshold case. The recovered $\log \left[J\left(\nu_{0}\right)\right],-22.47$, is $4 \sigma$ larger than the input. We will return to the discussion of the variable threshold in Section 4.5 .3 below.

### 4.5.2 HI Ionization Rate

As described in Paper II, solving for the HI ionization rate,

$$
\begin{equation*}
\Gamma=\int_{\nu_{0}}^{\infty} \frac{4 \pi J(\nu) \sigma_{H I}(\nu)}{h \nu} d \nu \mathrm{~s}^{-1} \tag{4.12}
\end{equation*}
$$

instead of $J\left(\nu_{0}\right)$ avoids the assumption that the spectral indicies of the QSOs and the background are identical. We modified our maximum likelihood code to use the values of $\alpha$ for each QSO listed in Table 4.3 to measure this quantity and the results are listed in Table 4.6. For objects with no available measured value of $\alpha$, we use $\alpha=2.02$, the extreme ultraviolet spectral index measured from a composite spectrum of 101 HST/FOS QSO spectra by Zheng et al. (1997). The result for lines above a constant $0.32 \AA$ rest equivalent width threshold is $\log (\Gamma)=-12.17_{-0.40}^{+0.50}$. This result is not substantially changed if we instead use $\alpha=1.76$, the value found from a composite of 184 QSO spectra from HST/FOS, GHRS, and STIS by Telfer et al. (2001), giving $\log (\Gamma)=-12.25_{-0.35}^{+0.47}$. We also find little change in the result if we assume $\alpha=2.02$ or $\alpha=1.76$ for all QSOs. The variable threshold data result in a high HI ionization rate, and this is discussed further in the following section. The constant threshold result is plotted in Figure 4.13. Evolution in the UV background is more apparent in the HI ionization rate than in the solutions for $J\left(\nu_{0}\right)$. The result at $z>1$ is 6.5
times larger than that at $z<1$. The values of $J\left(\nu_{0}\right)$ implied by these solutions for $\Gamma$ and a global source spectral index $\alpha_{\mathrm{s}}=1.8$ are also listed in Table 4.6.

We also parametrize the evolution of the HI ionization rate as a power law:

$$
\begin{equation*}
\Gamma(z)=A_{\mathrm{pl}}(1+z)^{B_{\mathrm{pl}}} \tag{4.13}
\end{equation*}
$$

and solve for the parameters $A_{\mathrm{pl}}$ and $B_{\mathrm{pl}}$ in both the constant and variable threshold cases. The values we find are shown as the dashed line in Figure 4.13 also listed in Table 4.6.

HM96 parametrize their models of the HI ionization rate with the function:

$$
\begin{equation*}
\Gamma(z)=A_{\mathrm{HM}}(1+z)^{B_{\mathrm{HM}}} \exp \left(\frac{-\left(z-z_{c}\right)^{2}}{S}\right) \tag{4.14}
\end{equation*}
$$

We combine our data set with that of Paper II to solve for the parameters $A_{\mathrm{HM}}, B_{\mathrm{HM}}$, $z_{c}$, and $S$. We find ( $\left.A_{\mathrm{HM}}, B_{\mathrm{HM}}, z_{c}, S\right)=\left(7.6 \times 10^{-13}, 0.35,2.07,1.77\right)$ for $\beta=1.46$ and $\left(A_{\mathrm{HM}}, B_{\mathrm{HM}}, z_{c}, S\right)=\left(3.2 \times 10^{-13}, 1.45,2.13,1.42\right)$ for $\beta=1.7$, while the parameters found by HM96 for $q_{0}=0.5$ are $\left(6.7 \times 10^{-13}, 0.43,2.30,1.95\right)$. These results are also represented by the solid curves in Figure 4.13, while the HM96 parametrization is shown by the dotted line for comparison.

### 4.5.3 Variable Equivalent Width Threshold

The variable threshold analysis yielded some unexpected results. As seen in the majority of the simulations, the values of $J\left(\nu_{0}\right)$ found were consistently larger than the values found using a constant equivalent width threshold, indicating that the inclusion of weaker lines suppresses the proximity effect. This is to be expected if clustering is occurring (Loeb \& Eisenstein 1995), which in itself is to be expected to be more prominent at low redshift than at high redshift. However, the suppression of the proximity effect by the inclusion of weak lines is somewhat counterintuitive from the perspective of the curve of growth. Most of the lines included in a constant threshold solution are on the flat part of the curve of growth. Therefore, though the ionizing
influence of the quasar may be translated directly into a change in the HI column density, as predicted by the BDO photoionization model, this will not necessarily result in a corresponding change in the line equivalent width. The solution for $z<1$ is nearly a factor of 3 larger than the the solution found in the case of a constant, $0.32 \AA$ equivalent width threshold. The solution for $z>1$ is a factor of $\sim 6$ larger than the constant threshold solution, with no well-defined $1 \sigma$ upper limit due to the flattening of the likelihood function towards high $J\left(\nu_{0}\right)$ This likelihood function for the total sample shows two peaks, the most prominent at $\log \left[J\left(\nu_{0}\right)\right]=-20.82$, the solution listed in Table 3.4, and a secondary peak at $\log \left[J\left(\nu_{0}\right)\right] \sim-18.4$.

This behavior is also exhibited, even more dramatically, in the solutions for the HI ionization rate, as discussed above. We conducted a jackknife resampling experiment (Babu \& Feigelson 1996, Efron 1982) to determine the source of these likelihood function peaks at large $\log (\Gamma)$, or $\log \left[J\left(\nu_{0}\right)\right]$.

Two objects, 0743-6719 ( $z_{\mathrm{em}}=1.508$ ) and 0302-2223 ( $z_{\mathrm{em}}=1.402$ ), are found from jackknife experiments to produce all of this effect. In the jackknife experiment, we perform the maximum likelihood calculation of $J\left(\nu_{0}\right) \mathrm{N}$ times, where N is the number of objects in the high redshift subsample. In each calculation, one object from the total sample is removed. The results of this experiment are shown in the histogram in Figure 4.14. The removal of 0743-6719 or 0302-2223 results in the two values of $\Gamma$ that are well-defined and that are in reasonable agreement with the value calculated at high redshift in the constant threshold case. Removing only the one line from 0743-6719 nearest the Ly- $\alpha$ emission line with $z_{\mathrm{abs}}=1.5058$ and observed equivalent width equal to $0.23 \AA$ results in $\Gamma=6.23 \times 10^{-12} \mathrm{~s}^{-1}$. This object was part of the HST Key Project sample (Jannuzi et al. 1998) and they cite no evidence of associated aborption in its spectrum. Removing only the one line from 0302-2223 nearest the Ly- $\alpha$ emission line with $z_{\mathrm{abs}}=1.3886$ and observed equivalent width equal to $0.27 \AA$ results in $\Gamma=8.14 \times 10^{-12} \mathrm{~s}^{-1}$. This object shows an absorption system at $z_{\text {abs }}=1.406$ and is classified as an associated absorber. No metal absorption is seen at
$z_{\mathrm{abs}}=1.3886$, though this absorber is within $5000 \mathrm{~km} \mathrm{~s}^{-1}$ of the QSO, the canonical associated absorber region. Removing both of these lines gives $\Gamma=3.88 \times 10^{-12}$ $s^{-1}$. Due to the small equivalent widths of both of these lines they are not included in the constant threshold analysis, and the solutions for $J\left(\nu_{0}\right)$ and $\Gamma$ for $z>1$ are well-defined.

It appears that this method has some trouble reliably recovering the background from a sample of absorption lines above an equivalent width threshold allowed to vary with $\mathrm{S} / \mathrm{N}$. As the method works well for the constant threshold case, we contend that the photoionization model, expressed in Equ. 4.3, used to create the likelihood function must not be an adequate model for the proximity effect when weak lines are included in the analysis. Liske \& Williger (2001) introduce a method for extracting $J\left(\nu_{0}\right)$ from QSO spectra based on flux statistics. We shall return to this topic in future work.

### 4.6 Discussion

### 4.6.1 Radio Loudness

As the results listed in Table 3.4 indicate, the inclusion of the four blazars and one BL Lac object, all at $z<1$, in our sample does not change the result significantly. However, there is much observational evidence that radio loud and radio quiet quasars inhabit different environments, namely that radio loud quasars reside in rich clusters while radio quiet quasars exist in galaxy environments consistent with the field (Stockton 1982, Yee \& Green 1984, 1987, Yee 1987, Yates, Miller, \& Peacock 1989, Ellingson, Yee, \& Green 1991, Yee \& Ellingson 1993, Wold et al. 2000, Smith, Boyle, \& Maddox 2000). If there is a corresponding increase in the number of $\mathrm{Ly}-\alpha$ absorption lines in the spectra of radio loud objects, this could cause the proximity effect to be suppressed, and the measured $\log \left[J\left(\nu_{0}\right)\right]$ to be artificially large. We have therefore divided our sample into radio loud and radio quiet subsamples using the ratio of radio
to UV flux to characterize the radio loudness,

$$
\begin{equation*}
\mathrm{RL}=\log [\mathrm{S}(5 \mathrm{GHz})] / \log [\mathbf{S}(1450 \AA)] . \tag{4.15}
\end{equation*}
$$

The value of RL for each object in our sample is listed in Table 4.3. A histogram of these values and the distribution of RL with $z$ for the sample objects are shown in Figure 4.15. The division between radio loud and radio quiet was chosen to be $\mathrm{RL}=1.0$. The resulting values of $\log \left[J\left(\nu_{0}\right)\right]$ for these subsamples are listed in Table 3.4. There is no significant trend for $\log \left[J\left(\nu_{0}\right)\right]$ to appear larger for radio loud objects than for radio quiet objects.

### 4.6.2 $\operatorname{Non-Zero~} \Omega_{\Lambda}$

We performed the maximum likelihood calculation for the case of a non-zero cosmological constant. This means that the observer-QSO and absorber-QSO luminosity distances that appear in the relationship between $\omega$ and $z$ (BDO) must be calculated numerically from the expression:

$$
\begin{equation*}
d_{L}=(1+z) \frac{c}{H_{0}} \int_{0}^{z} \frac{d z^{\prime}}{E\left(z^{\prime}\right)} \tag{4.16}
\end{equation*}
$$

where

$$
\begin{equation*}
E(z) \equiv \sqrt{\Omega_{\mathrm{M}}(1+z)^{3}+\Omega_{\mathrm{k}}(1+z)^{2}+\Omega_{\Lambda}}, \tag{4.17}
\end{equation*}
$$

(Peebles, 1993) as this integral cannot be reduced to an analytical form for $\Omega_{\mathrm{A}} \neq 0$.
The calculations in the sections above assume $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$. Here, we perform the maximum likelihood search for $J\left(\nu_{0}\right)$ using $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(0.3,0.7)$. For a QSO at $z=0.5$ with a Lyman limit flux density of $0.1 \mu \mathrm{Jy}$, an absorber at $z=0.48$, and an assumed background of $\log \left[J\left(\nu_{0}\right)\right]=-22$., this $\left(\Omega_{M}, \Omega_{\mathrm{A}}\right)$ results in a value of $\omega$ that is $\sim 25 \%$ smaller than that inferred in the $\Omega_{A}=0$ case. Unlike all the other solutions performed, we ignore redshift path associated with metal lines and use all redshifts between $z_{\min }^{q}$ and $z_{\max }^{q}$. This does not change the results significantly, but
cuts down the computation time substantially. The results are listed in Table 3.4 and are plotted in Figure 4.11. For comparison, we also give the solutions for $J\left(\nu_{0}\right)$ found using the standard parameters, $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$, with this redshift path neglected. We find that $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(0.3,0.7)$, does not change the value of $J\left(\nu_{0}\right)$ derived significantly from the value found using $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$.

We performed a slightly modified re-analysis of the Paper II sample of objects at $z \sim 2$ and found little effect at high redshift as well. The solution found for $\left(\Omega_{\mathrm{M}}, \Omega_{\Lambda}\right)=(1.0,0.0)$ was $\log \left[J\left(\nu_{0}\right)\right]=-21.09_{-0.17}^{+0.20}$, while for $\left(\Omega_{\mathrm{M}}, \Omega_{\Lambda}\right)=(0.3,0.7)$, we find $\log \left[J\left(\nu_{0}\right)\right]=-21.25_{-0.17}^{+0.20}$ for these data.

### 4.6.3 $d \mathcal{N} / d z$

In the case of a size distribution of Ly- $\alpha$ absorbers that is constant in redshift, the evolution of the number of $\mathrm{Ly}-\alpha$ absorption lines per unit redshift is given by:

$$
\begin{equation*}
d \mathcal{N} / d z=\mathcal{N}_{0}(1+z)^{2}\left[\Omega_{M}(1+z)^{3}+\left(1-\Omega_{M}-\Omega_{\Lambda}\right)(1+z)^{2}+\Omega_{\Lambda}\right]^{-0.5} \tag{4.18}
\end{equation*}
$$

(Sargent et al. 1980) where $\mathcal{N}_{0}$ equals the absorber cross section times the absorber comoving number density times the Hubble distance, $\pi r_{0}^{2} \phi_{0} c H_{0}^{-1}$. A plot of $d \mathcal{N} / d z$ versus $z$ for non-evolving Ly- $\alpha$ absorbers in $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$ and ( $0.3,0.7$ ) cosmologies is shown in Figure 4.17. It is clear that non-evolving models are too shallow to fit points at $z>1.7$, so the normalization is found from a fit to the FOS data. The FOS data at $z<1.7$ are consistent with a non-evolving population for $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$. The data are less consistent with a non-evolving concordance model in which $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(0.3,0.7)$, though not significantly so.

The number density evolution of Ly- $\alpha$ absorbers over the redshift range $z=0-5$ cannot be approximated with a single power law. There is a significant break in the slope of the line number density with respect to redshift, near $z=1.7$ (Weymann et al. 1998, Paper IV) though Kim, Cristiani, \& D'Odorico (2001) argue that the break occurs at $z=1.2$. Davé et al. (1999) show from hydrodynamical simulations
of the low redshift Ly- $\alpha$ forest, that the evolution of the line density is sensitive mainly to the HI photoionization rate, but also to the evolution of structure (cf. their Figure 7). The flattening of $d \mathcal{N} / d z$ observed by Weymann et al. (1998) is mostly attributed to a dramatic decline in $\Gamma(z)$ with decreasing $z$. Davé et al. (1999) derive an expression for the density of Ly- $\alpha$ forest lines per unit redshift as a function of the HI photoionization rate:

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=C\left[(1+z)^{5} \Gamma^{-1}(z)\right]^{\beta-1} H^{-1}(z) \tag{4.19}
\end{equation*}
$$

where $C$ is the normalization at some fiducial redshift which we choose to be $z=0$ and $\Gamma(z)$ can be expressed by Equ. 4.14.

We fit the FOS and MMT absorption line data, binned in $d \mathcal{N} / d z$ as presented in Paper IV and Scott et al. (2000a, Paper I), to this function in order to derive the parameters describing $\Gamma(z)$ implied by the evolution in Ly- $\alpha$ forest line density. We observe flattening of $d \mathcal{N} / d z$ at $z<1.7$, but not to the degree seen by Weymann et al. (1998) in the Key Project data. As described in Paper IV, we find $\gamma=0.54 \pm 0.21$, for lines above a $0.24 \AA$ threshold, while Weymann et al. (1998) measure $\gamma=0.15 \pm 0.23$. See Paper IV for more discussion of the significance and underlying causes of this difference. We find $\left(A_{\mathrm{HM}}, B_{\mathrm{HM}}, z_{c}, S\right)=\left(3.0 \times 10^{-12}, 0.61,5.5 \times 10^{-7}, 7.07\right)$ and $(1.9 \times$ $10^{-11}, 0.38,3.4 \times 10^{-7}, 6.21$ ) for ( $\Omega_{\mathrm{M}}, \Omega_{\Lambda}$ ) $=(1 ., 0$ ) and lines with rest equivalent widths above 0.24 and $0.32 \AA$ respectively. These fits to Equ. 4.19 are shown in Figure 4.18(a). In panel (b), we plot $\Gamma(z)$, as expressed in Equ. 4.14, evaluated using the parameters found from the fit to Equ. 4.19 above. The HM96 solution and the solution derived from the full FOS and MMT data sets are represented by the thick and thin solid lines respectively. The small values of $z_{c}$ derived from $d \mathcal{N} / d z$ above translate into ionization rates that do not decrease dramatically with decreasing redshift and result from the less pronounced flattening of $d \mathcal{N} / d z$ relative to the Key Project. These fits are particularly insensitive to the normalization, $A_{\mathrm{HM}}$, so the errors on this parameter are large. These fits should therefore not be interpreted
as measurements of $\Gamma(z)$ as reliable as those found directly from the absorption line data. But we find them instructive nonetheless. The observed $\Gamma(z)$ falls short of the ionization rate needed to fully account for the change in the Ly- $\alpha$ line density with redshift, indicating that if the value of $\gamma$ at low redshift is indeed slightly larger than that found by the Key Project, $d \mathcal{N} / d z$ may still be consistent with a non-evolving population of $\mathrm{Ly}-\alpha$ absorbers in the sense noted above, but the formation of structure in the low redshift universe must play a significant role in determining the character of the Ly- $\alpha$ forest line density.

### 4.6.4 Comparison with Previous Results

Proximity Effect: KF93 performed a similar measurement with a small subsample of this total sample- the HST Quasar Absorption Line Key Project data of Bahcall et al. (1993). We compare our result to that from Sample 2 of KF93, which was constructed from the Bahcall et al. (1993) data excluding one BAL quasar and all heavy element absorption systems. The Key Project sample has since been supplemented (Bahcall et al. 1996, Jannuzi et al. 1998) and those data have been included when appropriate in the complete archival sample of FOS spectra presented in Paper III.

The mean intensity KF93 derive from their Sample $2\left(b=35 \mathrm{~km} \mathrm{~s}^{-1}, \beta=1.48\right.$, $\gamma=0.21$ ) is $5.0_{-3.4}^{+20 .} \times 10^{-24} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$. This result is lower than ours for $z<1$ by a factor of $\sim 13$, though the errors are large on both results are large enough that they are consistent. We use 162 lines in our low redshift solution for $J\left(\nu_{0}\right), 65$ more than KF93.

Direct Measurements: Several authors have examined the sharp cutoffs observed in the HI disks of galaxies in the context of using these signatures to infer the local ionizing background (Maloney 1993, Corbelli \& Salpeter 1993, Dove \& Shull 1994). The truncations are modeled as arising primarily from photoionization of the disk gas by the local extragalactic background radiation field. Using 21 cm observations
(Corbelli, Scheider, \& Salpeter 1989, van Gorkom 1993) to constrain these models, limits on the local ionizing background are placed at $10^{4}<\Phi_{\text {ion }}<5 \times 10^{4} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$, where

$$
\begin{equation*}
\Phi_{\mathrm{ion}}=2 \pi \int_{0}^{1} \mu d \mu \int_{\nu_{0}}^{\infty} \frac{J_{\nu}}{h \nu} d \nu=\frac{\pi J\left(\nu_{0}\right)}{h \alpha_{s}} \tag{4.20}
\end{equation*}
$$

and where $J_{\nu}=I_{\nu}$ for an isotropic radiation field.
Additionally, narrow-band and Fabry-Perot observations of $\mathrm{H} \alpha$ emission from intergalactic clouds (Stocke et al. 1991, Bland-Hawthorn et al. 1994, Vogel et al. 1995, Donahue, Aldering, \& Stocke 1995) place limits of $\boldsymbol{\Phi}_{\text {ion }} \lesssim 10^{4} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$, or $J\left(\nu_{0}\right)<7.6 \times 10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ for $\alpha_{s}=1.8$, while results from measurements of Galactic high velocity clouds (Kutyrev \& Reynolds 1989, Songaila, Bryant, \& Cowie 1989, Tufte, Reynolds, \& Haffner 1998) imply $\boldsymbol{\Phi}_{\text {ion }} \lesssim 6 \times 10^{4} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$, though the ionization of high velocity clouds may be contaminated by a Galactic stellar contribution.

Tumlinson et al. (1999) have reanalyzed the 3C273/NGC3067 field using the $\mathrm{H} \alpha$ imaging data from Stocke et al. (1991) as well as new GHRS spectra of 3C273, in order to model the ionization balance in the absorbing gas in the halo of NGC3067. From this analysis, they derive the limits, $2600<\Phi_{\text {ion }}<10^{4} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$, or $10^{-23}<$ $J\left(\nu_{0}\right)<3.8 \times 10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ at $z=0.0047$. Weymann et al. (2001) have recently reported an upper limit of $\Phi_{\text {ion }}<1.01 \times 10^{4} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$, or $J\left(\nu_{0}\right)<$ $3.84 \times 10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ from Fabry-Perot observations of the intergalactic HI cloud, $1225+01$, for a face-on disk geometry. If an inclined disk geometry is assumed, this limit becomes $J\left(\nu_{0}\right)<9.6 \times 10^{-24} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$. These results are summarized in Figure 4.16. It is encouraging that the proximity effect value is consistent with the limits on the background set by these more direct estimates which are possible locally.

### 4.6.5 Comparison with Models

Haardt \& Madau (1996) calculated the spectrum of the UV background as a function of frequency and redshift using a model based on the integrated emission from QSOs alone. The QSO luminosity function is drawn from Pei (1995). The opacity of the intergalactic medium is computed from the observed redshift and column density distributions of Ly- $\alpha$ absorbers given by Equ. 4.2. The effects of attenuation and reemission of radiation by hydrogen and helium in $\mathrm{Ly}-\alpha$ absorbers are included in these models. Their result for $q_{0}=0.5$ and $\alpha_{s}=1.8$ at $z=0$ is $J\left(\nu_{0}\right)=1.6 \times 10^{-23}$ ergs $\mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$.

Fardal, Giroux, \& Shull (1998) compute opacity models for the intergalactic medium (IGM) based on high resolution observations of the high redshift Ly- $\alpha$ forest from several authors. Shull et al. (1999) extend the models of Fardal, Giroux, \& Shull (1998) to $z=0$, treating opacity of low redshift Ly- $\alpha$ forest from observations made with HST/GHRS (Penton et al. 2000a,b) and with HST/FOS (Weymann et al. 1998). Like Haardt \& Madau (1996), they also incorporate the observed redshift distribution of Lyman limit systems with $\log \left(\mathrm{N}_{\mathrm{HI}}\right)>17$ (Stengler-Larrea et al. 1995, Storrie-Lombardi et al. 1994). Their models also allow for a contribution from star formation in galaxies in addition to AGN. The QSO luminosity function again is taken to follow the form given by Pei (1995) with upper/lower cutoffs at $0.01 / 10 \mathrm{~L}$. QSO UV spectral indicies are assumed to equal 0.86 , while the ionizing spectrum at $\nu>\nu_{0}$ has $\alpha_{s}=1.8$. The contribution to the background from stars was normalized to the $\mathrm{H} \alpha$ luminosity function observed by Gallego et al. (1995) and the escape fraction of photons of all energies from galaxies was taken to be $\left\langle f_{\text {esc }}\right\rangle=0.05$. The full radiative transfer model described in Fardal, Giroux, \& Shull (1998) was used to calculate the contribution to the mean intensity by AGN, but not the contribution from stars, as they were assumed to contribute no flux above 4 Ryd, the energies at which the effects of IGM reprocessing become important. These authors find $J\left(\nu_{0}\right)=2.4 \times 10^{-23}$
ergs $\mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ at $z \sim 0$, with approximately equal contributions from AGN and stars, a value somewhat lower than our result for $z<1$, but which is allowed within the errors.

We estimate the contribution to the UV background from star-forming galaxies using the galaxy luminosity function of the Canada-France Redshift Survey (Lilly et al. 1995). At $z \sim 0.5$, we derive $J^{\text {gal }}\left(\nu_{0}\right)=1.5 \times 10^{-22} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1}$ $\mathrm{sr}^{-1}$, assuming $<f_{\text {esc }}>=1$. The HM96 models for the QSO contribution give $J^{\mathrm{QSO}}\left(\nu_{0}\right)=5.2 \times 10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ at $z \sim 0.5$. These estimates, and the range of measured $J\left(\nu_{0}\right)$ in this paper, $\sim 5-16 \times 10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ imply an escape fraction of UV photons from galaxies between $4 \%$ and $70 \%$. The $J\left(\nu_{0}\right)$ inferred from $d \mathcal{N} / d z$ in Section 4.6 .3 implies escape fractions well over $100 \%$.

Bianchi et al. (2001) make updated estimates of the mean intensity of the background with contributions from both QSOs and star-forming galaxies. Their models incorporate various values of the escape fraction of Lyman continuum photons from galaxies which are constant with redshift and wavelength. Our new results at $z<1.7$ are most consistent with their models of the QSO contribution alone, though some contribution from galaxies, ie. a small $\mathrm{f}_{\mathrm{esc}}$, is allowed within the uncertainties. At $z \sim 3.5$, recent results from Steidel, Pettini, \& Adelberger (2001) on the Lymancontinuum radiation from high redshift galaxies suggest that these sources become a more important component of the UV background at high redshift.

### 4.6.6 Systematics

Drawing on lessons learned from our work on high redshift objects in Paper II, we have made corrections for quasar systemic redshifts before performing the proximity effect analysis, as discussed in $\S 4.2$. This correction, $\sim 300 \mathrm{~km} \mathrm{~s}^{-1}$, was made to QSO redshifts measured from Ly- $\alpha$ emission for objects for which no systemic redshift measurement was available. For the low redshifts considered in this paper, redshifts
measured from [OIII], MgII, or Balmer emission lines were deemed suitable as QSO systemic redshift measurements.

We have removed known gravitational lenses from the sample. As discussed above, we perform the proximity effect analysis omitting and including spectra that show associated absorption and damped Ly- $\alpha$ absorption and determined that neither of these populations significantly biases our results.

Because we are working with low redshift data where line densities are low, we expect that blending has not contributed as strong a systematic effect as in the high redshift sample of Paper II. The curve-of-growth effects discussed in Paper II may still be present, since many lines in the sample have equivalent widths which place them on the flat part of the curve of growth.

However, the effects of clustering may be even more important at low redshift than at high redshift. Loeb \& Eisenstein (1995) showed how the fact that quasars reside in the dark matter potentials of galaxies and small groups of galaxies can influence the proximity effect signature. The peculiar velocities of matter clustered in these potentials can result in $\mathrm{Ly}-\alpha$ absorption at redshifts greater than the quasar emission redshift. We found that including associated absorbers in our sample did not significantly change our results. Recently, Pascarelle et al. (2001) report evidence for a lower incidence of $\mathrm{Ly}-\alpha$ absorption lines arising in the gaseous halos of galaxies in the vicinities of QSOs than in regions far from QSOs. They argue that galaxy-QSO clustering may lead proximity effect measurements to overestimate $J\left(\nu_{0}\right)$ at $z<1$ by a up to a factor of 20 . While we agree that most systematic effects in this type of analysis, including clustering, will lead to overestimates of $J\left(\nu_{0}\right)$, the agreement between our results and the direct measurements discussed in Section 4.6 .4 give us confidence that our results are not biased by this large a factor.

The hydrodynamic simulations of the low redshift Ly- $\alpha$ forest of Davé et al. (1999) indicate that, at low redshift, structures of the same column density correspond to larger overdensities and more advanced dynamical states than at high redshift. For
a $\left(\Omega_{\mathrm{M}}, \Omega_{\Lambda}\right)=(0.4,0.6)$ cosmology, an equivalent width limit of $0.32 \AA$ corresponds to an overdensity of $\sim 1.4$ at $z \sim 3$, while at $z \sim 0.6$, this limit corresponds to $\rho_{H} / \overline{\rho_{H}} \sim 13$. This may have implications on the clustering of Ly- $\alpha$ absorption lines around QSOs and hence on the values of $J\left(\nu_{0}\right)$ derived from the proximity effect. It is possible that we are seeing this clustering effect in the variable threshold solution at $z>1$, in which the two highest $\omega(z)$ lines in the sample are responsible for the inability to isolate a reasonable maximum likelihood $J\left(\nu_{0}\right)$.

### 4.7 Summary

We have analyzed a set of 151 QSOs and 906 Ly- $\alpha$ absorption lines, the subset of the total data set presented in Paper III that is appropriate for the proximity effect. The primary results of this paper are as follows:
(1) At low redshift, Balmer, [OIII], and Mg II emission lines are reasonable indicators of QSO systemic redshifts. Ly- $\alpha$ emission is blueshifted by $\sim 300 \mathrm{~km} \mathrm{~s}^{-1}$ with respect to [OIII].
(2) The value of $J\left(\nu_{0}\right)$ is observed to increase with redshift over the redshift range of the sample data, $0.03<z<1.67$. Dividing the sample at $z=1$, we find $J\left(\nu_{0}\right)=$ $6.5_{-1.6}^{+38 .} \times 10^{-23} \mathrm{ergs} \mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$, at low redshift and $J\left(\nu_{0}\right)=1.0_{-0.2}^{+3.8} \times 10^{-22}$ ergs $\mathrm{s}^{-1} \mathrm{~cm}^{-2} \mathrm{~Hz}^{-1} \mathrm{sr}^{-1}$ at high redshift.
(3) The inclusion of blazars at $z<1$ has no significant effect on the result. There is no significant difference between the values of $J\left(\nu_{0}\right)$ derived from radio loud (RL $>1.0$ ) and radio quiet ( $\mathrm{RL}<1.0$ ) objects, indicating that the observed richness of quasar environments does not distinctly bias the proximity effect analysis.
(4) Using information measured and gathered from the literature on each QSO's UV spectral index and solving for the HI ionization rate, yields $1.9 \times 10^{-13} \mathrm{~s}^{-1}$ for $z<1$ and $1.3 \times 10^{-12} \mathrm{~s}^{-1}$ for and $z>1$. Solving directly for the parameters $\left(A_{\mathrm{HM}}, B_{\mathrm{HM}}, z_{\mathrm{c}}, S\right)$ in the HM96 parametrization of $\Gamma(z)$ using the HST/FOS data
presented in Paper III combined with the high redshift, ground-based data presented in Papers I and II results in $\left(A_{\mathrm{HM}}, B_{\mathrm{HM}}, z_{c}, S\right)=\left(7.6 \times 10^{-13}, 0.35,2.07,1.77\right)$ for $\beta=1.46$ and $\left(A_{\mathrm{HM}}, B_{\mathrm{HM}}, z_{c}, S\right)=\left(3.2 \times 10^{-13}, 1.45,2.13,1.42\right)$ for $\beta=1.7$ for $0.03<z<3.8$.
(5) Allowing for a varying equivalent width threshold across each QSO spectrum results in consistently higher values of $J\left(\nu_{0}\right)$ than are found from the constant threshold treatments. At $z>1$, the variable threshold solution is not well-constrained. Jackknife experiments indicate that this is due to the objects 0743-6719 and 03022223, namely the highest $\omega(z)$ absorption lines in each of their spectra.
(6) Allowing for a cosmology in which $\left(\Omega_{\mathrm{M}}, \Omega_{\Lambda}\right)=(0.3,0.7)$, rather than ( $1 ., 0$. ) has no significant effect on the value of $J\left(\nu_{0}\right)$ derived from these data.
(7) The $z<1$ result is in agreement with the range of values of the mean intensity of the hydrogen-ionizing background allowed by a variety of local estimates, including $\mathrm{H} \alpha$ imaging and modeling of galaxy HI disk truncations. To within the uncertainty in the measurement, this result agrees with the one previous proximity effect measurement of the low redshift UV background (KF93). These results are consistent with calculated models based upon the integrated emission from QSOs alone (HM96) and with models which include both QSOs and starburst galaxies (Shull et al. 1999). The uncertainties do not make a distinction between these two models possible.
(8) The results presented here tentatively confirm the IGM evolution scenario provided by large scale hydrodynamic simulations (Davé et al. 1999). This scenario, which is successful in describing many observed properties of the low redshift IGM, is dependent upon an evolving $J\left(\nu_{0}\right)$ which decreases from $z=2$ to $z=0$. However, the low redshift UV background required to match the observations of the evolution of the Ly- $\alpha$ forest line density is larger than found from the data, indicating that structure formation is playing a role in this evolution as well. Our results and the work of others are summarized in Figure 4.16. We find some evidence of evolution in $J\left(\nu_{0}\right)$, though it appears that even larger data sets, especially at $z<1$ and/or improved
proximity effect ionization models will be required to improve the significance.

Table 4.1: Sample QSOs and Emission Line Redshifts

| QSO ${ }^{1}$ | NED description | Ly- $\alpha$ <br> (a) | MgII <br> (b) | OIII <br> (c) | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| 0003+1553 | opt.var. | 0.4497 | 0.4502 | 0.4503 |  | (1) | (2) | (3) |  |
| $0003+1955$ | opt.var. | 0.0264 | 0.0264 | 0.0261 | $\ldots$ | (1) | (1) | (4) |  |
| $0007+1041$ | opt.var. | 0.0902 | 0.0890 | 0.089 | 0.0895 | (1) | (1) | (5) | (6) |
| $0015+1612$ | RQQ | 0.5492 |  |  |  | (1) |  |  |  |
| $0017+0209$ | LINER | 0.3994 |  |  | $\ldots$ | (1) |  |  |  |
| $0024+2225$ |  | 1.1081 | 1.1096 |  |  | (1) | (7) |  |  |
| $0026+1259$ | Syl | 0.1453 | 0.1463 | 0.1452 | 0.1458 | (1) | (1) | (5) | (6) |
| $0042+1010$ |  | 0.5854 | 0.583 | 0.586 | 0.584 | (1) | (8) | (8) | (8) |
| $0043+0354$ | BAL? ${ }^{2}$ | 0.3803 | ... | ... | ... | (1) |  |  |  |
| $0044+0303$ | Sy1? | 0.6219 | 0.6222 | $\ldots$ | ... | (1) | (2) |  |  |
| $0050+1225$ | Compact,Syl | 0.0594 | ... | ... | $\ldots$ | (1) |  |  |  |
| $0100+0205$ | opt.var. | 0.3937 | $\ldots$ | 0.3936 | $\ldots$ | (1) |  | (3) |  |
| 0102-2713 | ... | 0.7763 | $\ldots$ | ... | $\ldots$ | (1) |  |  |  |
| 0107-1537 | $\ldots$ | 0.8574 | ... | $\ldots$ |  | (1) |  |  |  |
| 0112-0142 ${ }^{3}$ |  | 1.3739 | 1.3727 | $\ldots$ | $\ldots$ | (1) | (1) |  |  |
| $0115+0242^{3}$ | opt.var. | 0.6652 | 0.6700 |  |  | (1) | (9) |  |  |
| $0117+2118$ | ... | 1.4925 | 1.499 | 1.504 | 1.499 | (1) | (10) | (11) | (11) |
| 0121-5903 | Sy 1 | 0.0461 | 0.0462 | 0.044 | ... | (1) | (1) | (5) |  |
| 0122-0021 | opt.var.,LPQ | 1.0710 | 1.0895 |  |  | (1) | (12) |  |  |
| $0137+0116$ | opt.var. | 0.2622 | ... | 0.2631 | 0.2644 | (1) |  | (1) | (1) |
| 0159-1147 | opt.var.,Syl | 0.6683 | 0.6696 | ... | ... | (1) | (13) |  |  |
| 0214+1050 | opt.var. | 0.4068 |  | 0.407 |  | (1) |  | (14) |  |
| 0232-0415 | opt.var. | 1.4391 | 1.4434 | ... |  | (1) | (1) |  |  |
| 0253-0138 ${ }^{3}$ |  | 0.8756 |  | $\ldots$ |  | (1) |  |  |  |
| 0254-3327B | opt.var. | 1.916 | $\ldots$ | $\ldots$ | $\ldots$ | (15) |  |  |  |

Table 4.1: Sample QSOs and Emission Line Redshifts (Continued)

| QSO ${ }^{1}$ | NED description | Ly- $\alpha$ <br> (a) | MgII <br> (b) | OIII <br> (c) | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| 0302-2223 | DLAs | 1.4021 |  |  |  | (1) |  |  |  |
| 0333+3208 | opt.var.,LPQ | 1.2642 | 1.264 | $\ldots$ |  | (1) | (7) |  |  |
| 0334-3617 ${ }^{3}$ |  | 1.1085 |  |  |  | (1) |  |  |  |
| 0349-1438 |  | 0.6155 | 0.615 | $\ldots$ | 0.6206 | (1) | (16) |  | (1) |
| 0355-4820 |  | 1.0058 | 1.005 |  |  | (1) | (2) |  |  |
| 0403-1316 ${ }^{3}$ | opt.var.,HPQ | 0.5705 |  | 0.571 |  | (1) |  | (14) |  |
| 0405-1219 | opt.var.,HPQ | 0.5717 | 0.5730 | 0.573 | 0.5731 | (1) | (16) | (14) | (16) |
| 0414-0601 | opt.var. | 0.7739 | 0.773 | 0.774 | ... | (1) | (2) | (5) |  |
| 0420-0127 | blazar, HPQ | 0.9122 | 0.9162 | ... | $\ldots$ | (1) | (13) |  |  |
| 0439-4319 |  | 0.5932 |  |  |  | (1) |  |  |  |
| 0454-2203 | DLAs,LPQ | 0.5327 | 0.5350 | 0.534 | $\ldots$ | (1) | (2) | (14) |  |
| 0454+0356 | DLAs | 1.3413 | 1.3490 |  |  | (1) | (10) |  |  |
| 0518-4549 | Syl | 0.0355 | 0.0341 | $\ldots$ | 0.0339 | (1) | (1) |  | (17) |
| 0537-4406 ${ }^{3}$ | BL Lac, HPQ | 0.8976 | 0.8926 | $\ldots$ |  | (1) | (18) |  |  |
| 0624+6907 | ... | 0.3663 | 0.3687 | 0.3710 | 0.3698 | (1) | (1) | (1) | (1) |
| 0637-7513 | Syl | 0.6522 | 0.6565 | ... | 0.6570 | (1) | (18) |  | (18) |
| $0710+1151^{3}$ | opt.var. | 0.7712 |  |  |  | (1) |  |  |  |
| $0742+3150$ | Syl | 0.4589 | 0.462 | 0.461 | 0.4620 | (1) | (19) | (14) | (10) |
| 0743-6719 | opt.var. | 1.5109 | 1.5089 | ... | 1.511 | (1) | (20) |  | (21) |
| 0827+2421 | blazar, HPQ | 0.9363 | 0.94 |  | 0.942 | (1) | (7) |  | (7) |
| $0844+3456$ | Syl | 0.0637 | 0.0646 | 0.064 | ... | (1) | (1) | (5) |  |
| $0848+1623$ | opt.var. | ... | 1.9220 | ... | ... |  | (7) |  |  |
| $0850+4400$ | , | 0.5132 | 0.5142 |  | 0.5150 |  | (1) |  | (1) |
| 0859-1403 ${ }^{3}$ | blazar | 1.3338 | 1.3381 |  | 1.341 | (1) | (13) |  | (21) |
| $0903+1658^{3}$ | opt.var. | 0.4108 | 0.4106 | 0.4114 | ... | (1) | (22) | (22) |  |

Table 4.1: Sample QSOs and Emission Line Redshifts (Continued)

| $\mathrm{QSO}^{1}$ | NED description | Ly- $\alpha$ <br> (a) | $\overline{\mathrm{MgII}}$ <br> (b) | OIII <br> (c) | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| 0907-0920 ${ }^{3}$ |  | $0.630^{4}$ |  |  |  |  |  |  |  |
| 0916+5118 |  | 0.5520 | 0.5525 | $\ldots$ | 0.5536 |  | (1) |  | (1) |
| $0923+3915^{3}$ | opt.var.,Sy1,LPQ | 0.6986 | 0.6990 | $\ldots$ |  | (1) | (24) |  |  |
| $0935+4141$ |  | $1.937^{4}$ | ... | $\ldots$ |  |  |  |  |  |
| $0945+4053$ | LPQ | 1.2479 | 1.2506 | $\ldots$ |  | (1) | (19) |  |  |
| $0947+3940$ | Sy1 | 0.2057 |  | 0.2059 |  | (1) |  | (25) |  |
| 0953+4129 | Syl? | 0.2331 |  | 0.247 | 0.2326 | (1) |  | (25) | (25) |
| $0954+5537{ }^{3}$ | blazar, HPQ | 0.9005 | 0.9025 | ... |  | (1) | (1) |  |  |
| 0955+3238 | opt.var.,Syl. 8 | 0.5281 | ... | 0.531 | 0.5309 |  |  | (14) | (10) |
| 0958+5509 | ... | 1.7569 | 1.7582 | ... | ... | (10) | (7) |  |  |
| 0959+6827 | $\ldots$ | 0.7663 | 0.7724 | $\ldots$ | $\ldots$ | (1) | (1) |  |  |
| $1001+0527$ |  | 0.1589 | 0.1605 | $\ldots$ | 0.160 | (1) | (1) |  | (25) |
| $1001+2239$ | $\ldots$ | 0.9766 | ... | $\ldots$ | ... | (1) |  |  |  |
| $1001+2910$ | AGN | 0.3285 | ... | $\ldots$ | 0.3293 | (1) |  |  | (1) |
| $1007+4147$ | $\ldots$ | 0.6110 | 0.6125 | $\ldots$ |  | (1) | (13) |  |  |
| $1008+1319$ | $\ldots$ | 1.3012 | 1.2968 | ... |  | (1) | (1) |  |  |
| $1010+3606$ | Syl | 0.0785 | ... | 0.079 | $\ldots$ | (1) |  | (5) |  |
| 1026-004A | ... | 1.4349 | $\ldots$ | ... | $\ldots$ | (1) |  |  |  |
| 1026-004B | $\cdots$ | 1.5253 | ... | $\ldots$ |  | (1) |  |  |  |
| 1038+0625 | opt.var.,LPQ | 1.2667 | 1.272 | $\ldots$ | $\ldots$ | (1) | (7) |  |  |
| 1049-0035 | Sy1 | 0.3580 | 0.360 | $\ldots$ | 0.3605 | (1) | (5) |  | (10) |
| $1055+2007$ | opt.var. | 1.1136 | 1.1165 | $\ldots$ |  | (1) | (13) |  |  |
| $1100+7715$ | opt.var.,AGN | 0.3120 |  | 0.324 | 0.339 | (1) |  | (25) | (25) |
| $1104+1644$ | opt.var.,Syl | 0.6294 | $\ldots$ | 0.630 | 0.6307 | (1) |  | (5) | (6) |
| $1114+4429$ | Syl | 0.1448 | 0.1442 | 0.143 | ... | (1) | (1) | (25) |  |

Table 4.1: Sample QSOs and Emission Line Redshifts
(Continued)

| QSO $^{1}$ | NED description | Ly- $\alpha$ <br> (a) | MgII <br> (b) | OIII <br> (c) | Balmer <br> (d) | References |  |  |  |
| :--- | :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | (a) | (b) | (c) | (d) |  |  |  |  |
| $1115+4042$ | Sy1 | 0.1545 | 0.1552 | $\ldots$ | 0.156 | $(1)$ | $(1)$ |  | $(25)$ |
| $1116+2135$ | E2,Sy1? | $\ldots$ | $\ldots$ | 0.1768 | 0.1756 |  |  | $(25)$ | $(25)$ |
| $1118+1252$ | opt.var. | 0.6823 | $\ldots$ | $\ldots$ | $\ldots$ | $(1)$ |  |  |  |
| $1127-1432^{3}$ | blazar,LPQ | 1.1824 | 1.2121 | $\ldots$ | $\ldots$ | $(1)$ | $(18)$ |  |  |
| $1130+1108$ | $\ldots$ | 0.5065 | $\ldots$ | 0.5110 | 0.5104 | $(1)$ |  | $(1)$ | $(1)$ |
| $1136-1334$ | Sy1 | 0.5551 | 0.5571 | $\ldots$ | 0.5604 | $(1)$ | $(18)$ |  | $(18)$ |
| $1137+6604$ | opt.var.,LPQ | 0.6449 | 0.6448 | 0.646 | $\ldots$ | $(1)$ | $(13)$ | $(5)$ |  |
| $1138+0204$ | $\ldots$ | 0.3789 | $\ldots$ | 0.3820 | 0.3831 | $(1)$ |  | $(1)$ | $(1)$ |
| $1148+5454$ | opt.var. | 0.9688 | 0.9777 | $\ldots$ | $\ldots$ | $(1)$ | $(10)$ |  |  |
| $1150+4947$ | opt.var. | 0.3334 | 0.333 | 0.333 | 0.333 | $(1)$ | $(26)$ | $(26)$ | $(26)$ |
| $1156+2123$ | $\ldots$ | 0.3464 | $\ldots$ | 0.3475 | 0.3459 | $(1)$ |  | $(1)$ | $(1)$ |
| $1156+2931$ | blazar,HPQ | 0.7225 | 0.7281 | $\ldots$ | $\ldots$ | $(1)$ | $(1)$ |  |  |
| $1206+4557$ | $\ldots$ | 1.1596 | 1.164 | $\ldots$ | $\ldots$ | $(1)$ | $(7)$ |  |  |
| $1211+1419$ | RQQ,Sy1 | 0.0802 | 0.0805 | 0.0807 | 0.0810 | $(1)$ | $(1)$ | $(25)$ | $(25)$ |
| $1214+1804$ | $\ldots$ | 0.3719 | $\ldots$ | $\ldots$ | 0.3726 | $(1)$ |  |  | $(1)$ |
| $1215+6423$ | $\ldots$ | 1.2981 | $\ldots$ | $\ldots$ | $\ldots$ | $(1)$ |  |  |  |
| $1216+0655$ | opt.var. | 0.3312 | 0.3302 | 0.334 | 0.3374 | $(1)$ | $(25)$ | $(5)$ | $(25)$ |
| $1219+0447$ | AGN | 0.0953 | 0.0931 | $\ldots$ | $\ldots$ | $(1)$ | $(1)$ |  |  |
| $1219+7535^{3}$ | SB(r)ab pec,Sy1 | 0.0701 | 0.0713 | 0.071 | $\ldots$ | $(1)$ | $(1)$ | $(5)$ |  |
| $1226+0219$ | blazar,Sy1,LPQ | 0.156 | $\ldots$ | 0.157 | 0.158 | $(1)$ |  | $(27)$ | $(27)$ |
| $1229-0207$ | DLAs,blazar,LPQ | 1.0406 | 1.0439 | $\ldots$ | $\ldots$ | $(1)$ | $(13)$ |  |  |
| $1230+0947^{3}$ | $\ldots$ | 0.4176 | $\ldots$ | 0.4162 | 0.4153 | $(1)$ |  | $(1)$ | $(1)$ |
| $1241+1737$ | $\ldots$ | 1.2807 | 1.282 | $\ldots$ | $\ldots$ | $(1)$ | $(7)$ |  |  |
| $1247+2647$ | AGN | 2.0394 | $\ldots$ | $\ldots$ | $\ldots$ | $(10)$ |  |  |  |
| $1248+3032$ | $\ldots$ | 1.0607 | $\ldots$ | $\ldots$ | $\ldots$ | $(1)$ |  |  |  |

Table 4.1: Sample QSOs and Emission Line Redshifts (Continued)

| $\mathrm{QSO}^{1}$ | NED description | $\overline{\mathrm{L} y-\alpha}$ <br> (a) | MgII <br> (b) | OIII <br> (c) | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| 1248+3142 |  |  | 1.029 |  |  |  | (28) |  |  |
| $1248+4007$ | $\ldots$ | 1.0256 | 1.033 | $\ldots$ | ... | (1) | (7) |  |  |
| $1249+2929$ |  | 0.8205 | ... | $\ldots$ |  | (1) |  |  |  |
| $1250+3122$ |  | 0.7779 |  |  |  | (1) |  |  |  |
| 1252+1157 | opt.var. | 0.8701 |  |  |  | (1) |  |  |  |
| 1253-0531 | BL Lac, HPQ | 0.5367 | 0.5366 | 0.5356 | 0.536 | (1) | (29) | (29) | (29) |
| 1257+3439 | opt.var. | 1.3760 | 1.376 | ... | ... | (1) | (7) |  |  |
| $1258+2835$ | ... | 1.3611 | ... | $\ldots$ |  | (1) |  |  |  |
| $1259+5918$ |  | 0.4679 | 0.4717 | ... | 0.4853 | (1) | (25) |  | (25) |
| 1302-1017 | E4?,opt.var. | 0.2770 | 0.2867 | 0.278 | 0.2868 | (1) | (12) | (5) | (6) |
| $1305+0658$ | ... | 0.6009 | 0.5999 | ... | ... | (1) | (1) |  |  |
| 1309+3531 | Sab,Syl | 0.1841 | ... | 0.184 | 0.183 | (1) |  | (25) | (25) |
| $1317+2743$ | ... | 1.0082 | 1.016 | ... | ... | (1) | (7) |  |  |
| $1317+5203^{3}$ | blazar | 1.0550 | 1.0555 | $\ldots$ | ... | (1) | (7) |  |  |
| $1318+2903$ | opt.var. | 0.5469 | ... | $\ldots$ | $\ldots$ | (1) |  |  |  |
| $1320+2925$ | . | 0.9601 | 0.972 | $\ldots$ | ... | (1) | (7) |  |  |
| $1322+6557$ | Sy1 | 0.1676 |  | $\ldots$ | 0.1684 | (1) |  |  | (25) |
| $1323+6530$ | ... | 1.6227 | 1.6233 | $\ldots$ | ... | (1) | (30) |  |  |
| 1327-2040 | $\cdots$ | 1.1682 | 1.170 | $\ldots$ | ... | (1) | (18) |  |  |
| $1328+3045$ | DLAs | 0.8466 | 0.8508 | ... | $\ldots$ | (1) | (13) |  |  |
| $1329+4117$ | ... | 1.9351 | . |  |  | (10) |  |  |  |
| $1333+1740$ | $\ldots$ | 0.5464 | 0.5546 | ... | $\ldots$ | (1) | (25) |  |  |
| $1351+3153$ | $\ldots$ | 1.3170 | 1.3382 | .. |  | (1) | (31) |  |  |
| $1351+6400$ | Syl | 0.0886 | 0.0884 | 0.087 | 0.089 | (1) | (1) | (25) | (25) |
| $1352+0106$ | $\ldots$ | 1.1200 | ... | ... | ... | (1) |  |  |  |

Table 4.1: Sample QSOs and Emission Line Redshifts (Continued)

| QSO ${ }^{1}$ | NED description | Ly- $\alpha$ <br> (a) | $\overline{\mathrm{MgII}}$ <br> (b) | $\overline{\mathrm{O} I I I}$ <br> (c) | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| 1352+1819 | Syl | 0.1508 | 0.1514 | 0.1572 | 0.1538 | (1) | (1) | (25) | (25) |
| $1354+1933$ | opt.var. | 0.7190 | 0.718 | 0.719 | ... | (1) | (7) | (5) |  |
| $1356+5806^{3}$ |  | 1.3741 | 1.370 | ... |  | (1) | (7) |  |  |
| $1401+0952^{3}$ | $\ldots$ | 0.4363 | ... | $\ldots$ |  | (1) |  |  |  |
| $1404+2238$ | Sy | 0.0966 | 0.0978 | $\ldots$ | 0.098 | (1) | (1) |  | (25) |
| $1407+2632$ |  | 0.95 | 0.946 |  | 0.958 | (1) | (32) |  | (32) |
| $1415+4509$ | $\ldots$ | 0.1145 | 0.1142 | 0.1143 | 0.1139 | (1) | (1) | (25) | (25) |
| 1416+0642 | $\ldots$ | 1.4339 |  | ... | 1.442 | (1) |  |  | (21) |
| 1424-1150 |  | 0.8033 | 0.8037 | $\ldots$ | $\ldots$ | (1) | (18) |  |  |
| $1425+2645$ | opt.var. | 0.3634 | $\ldots$ | ... | 0.3644 | (1) |  |  | (10) |
| $1427+4800$ | Syl | 0.2215 | $\ldots$ | 0.2203 | 0.2246 | (1) |  | (25) | (25) |
| 1435-0134 |  | 1.3099 |  |  |  | (1) |  |  |  |
| $1440+3539$ | compact | 0.0764 | 0.0772 | 0.0777 | 0.0772 | (1) | (1) | (25) | (25) |
| $1444+4047$ | E1? | 0.2659 | ... | 0.2672 | 0.267 | (1) |  | (3) | (5) |
| $1512+3701$ | Syl? | 0.3704 | 0.3734 | 0.371 | 0.3715 | (1) | (2) | (5) | (6) |
| $1517+2356$ | ... | 1.9037 | ... | $\ldots$ | ... | (10) |  |  |  |
| $1517+2357$ | $\ldots$ | $1.834^{4}$ | .. | $\ldots$ | ... |  |  |  |  |
| 1521+1009 | $\ldots$ | 1.3210 | 1.332 | $\ldots$ | $\ldots$ | (1) | (7) |  |  |
| $1538+4745$ | $\ldots$ | 0.7704 | 0.7711 | $\ldots$ | ... | (1) | (7) |  |  |
| $1544+4855$ |  | 0.3985 | ... | $\ldots$ | 0.4010 | (1) |  |  | (2) |
| $1555+3313^{3}$ |  | 0.9402 | 0.9427 | .. | ... | (1) | (31) |  |  |
| $1611+3420^{3}$ | blazar,LPQ | 1.3968 | 1.3997 | $\ldots$ | $\ldots$ | (1) | (33) |  |  |
| $1618+1743$ | opt.var. | 0.5549 | 0.5560 | 0.555 | $\ldots$ | (1) | (14) | (13) |  |
| $1622+2352$ | opt.var. | 0.9258 | 0.925 |  |  | (1) | (7) |  |  |
| $\underline{1626+5529}$ | Sy1 | 0.1315 | 0.1325 | 0.132 | 0.133 | (1) | (1) | (25) | (25) |

Table 4.1: Sample QSOs and Emission Line Redshifts (Continued)

| $\mathrm{QSO}^{1}$ | NED description | Ly- $\alpha$ <br> (a) | $\overline{\mathrm{MgII}}$ <br> (b) | $\begin{gathered} \text { OIII } \\ \text { (c) } \\ \hline \end{gathered}$ | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| $1630+3744$ |  | 1.4712 | 1.478 | 1.474 | 1.478 | (1) | (10) | (11) | (27) |
| $1634+7037$ |  | 1.3338 | 1.338 | 1.336 | 1.342 | (1) | (10) | (11) | (27) |
| $1637+5726^{3}$ | LPQ | 0.7499 | 0.750 |  | 0.751 | (1) | (7) |  | (5) |
| $1641+3954^{3}$ | opt.var., $\mathrm{HPQ}^{5}$ | 0.5946 | 0.5954 | 0.593 |  | (1) | (14) | (2) |  |
| $1704+6048$ | opt.var. | 0.3694 | 0.3704 | 0.372 | $\ldots$ | (1) | (2) | (5) |  |
| $1715+5331$ |  | 1.9371 | 1.932 |  | $\ldots$ | (10) | (7) |  |  |
| $1718+4807$ |  | 1.0809 | 1.0828 |  |  | (1) | (7) |  |  |
| $1803+7827$ | BL Lac | 0.6840 |  | 0.6797 |  | (1) |  |  | (23) |
| $1821+6419$ | Syl | 0.2957 | $\cdots$ | 0.297 | ... | (1) |  | (5) |  |
| 1845+7943 | opt.var.,BLRG,Sy1 | 0.0567 | 0.0548 | ... |  | (1) | (1) |  |  |
| 2112+0556 |  | 0.4585 | ... | $\ldots$ | 0.460 | (1) |  |  | (5) |
| 2128-1220 | opt.var.,LPQ,Sy 1 | 0.4988 | 0.5000 | 0.499 | 0.5028 | (1) | (2) | (14) | (6) |
| 2135-1446 | E1,opt.var.,Syl | 0.2016 |  | 0.200 | 0.199 | (1) |  | (14) | (34) |
| $2141+1730$ | opt.var.,LPQ,Sy 1 | 0.2124 | $\ldots$ | 0.211 | ... | (1) |  | (14) |  |
| $2145+0643$ | opt.var.,LPQ | 0.9997 | 1.000 | ... |  | (1) | (7) |  |  |
| 2155-3027 ${ }^{3}$ | opt.var.,BL Lac | $0.116^{4}$ | ... | , | $\ldots$ |  |  |  |  |
| $2201+3131^{3}$ | LPQ | 0.2953 | 0.2981 | 0.295 | 0.2979 | (1) | (16) | (5) | (16) |
| 2216-0350 ${ }^{3}$ | opt.var.,LPQ | 0.8997 | 0.900 |  | ... | (1) | (7) |  |  |
| 2223-0512 ${ }^{3}$ | opt.var.,HPQ,BL Lac | 1.4037 |  | $\ldots$ | $\ldots$ | (1) |  |  |  |
| $2230+1128^{3}$ | blazar,HPQ | 1.0367 | 1.0379 | $\ldots$ | ... | (1) | (13) |  |  |
| 2243-1222 | opt.var.,HPQ | 0.6257 | 0.6297 |  | ... | (1) | (17) |  |  |
| $2251+1120$ | opt.var. |  | 0.322 | 0.326 | 0.3255 |  | (34) | (5) | (10) |
| $2251+1552$ | blazar, HPQ | 0.8557 | ... | ... | ... | (1) |  |  |  |
| 2251-1750 | opt.var.,Sy1 | 0.0651 | 0.0637 | 0.064 | ... | (1) | (1) | (5) |  |
| 2300-6823 | $\ldots$ | 0.5149 | 0.511 | 0.516 | 0.512 | (1) | (35) | (35) | (35) |

Table 4.1: Sample QSOs and Emission Line Redshifts (Continued)

| QSO ${ }^{1}$ | NED description | Ly- $\alpha$ <br> (a) | $\overline{\mathrm{MgII}}$ <br> (b) | OIII <br> (c) | Balmer <br> (d) | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | (a) | (b) | (c) | (d) |
| 2340-0339 |  | 0.8948 | 0.893 | $\ldots$ |  | (1) | (7) |  |  |
| 2344+0914 | opt.var.,Sy1 | 0.6710 | 0.6722 | 0.673 | 0.6731 | (1) | (16) | (5) | (16) |
| 2352-3414 | opt.var. | 0.7060 | 0.7063 | $\ldots$ | ... | (1) | (2) |  |  |

${ }^{1}$ See Paper III, Table 1 for alternate names
${ }^{2}$ We classify this as an associated absorber, see Paper III
${ }^{3}$ Observed only with pre-COSTAR FOS and A-1 aperture
${ }^{4}$ Redshift from Knezek \& Bregman 1998 (0907-0920), Green et al. 1986 (0935+4141), Hewitt \& Burbidge 1987 (1517+2357), Falomo et al. 1993 (2155-3027)
${ }^{5}$ Classified as blazar by Kinney et al. 1991
References:
(1) This paper; (2) Tytler et al. 1987; (3) Stockton \& MacKenty 1987;
(4) de Robertis 1985; (5) Corbin \& Boroson 1996; (6) Zheng \& Sulentic 1990;
(7) Steidel \& Sargent 1991; (8) Smith et al. 1977; (9) Cristiani \& Koehler 1987;
(10) Tytler \& Fan 1992; (11) Nishihara et al. 1997; (12) Browne et al. 1975;
(13) Aldcroft et al. 1994; (14) Corbin 1997; (15) Bolton et al. 1976; (16) Gaskell 1982;
(17) Basu 1994; (18) Wilkes 1986; (19) Wills \& Wills 1976; (20) di Serego-Alighieri et al. 1994;
(21) Cheng et al. 1990; (22) Lynds et al. 1966; (23) Lawrence et al. 1996;
(24) Burbidge \& Kinman 1966; (25) Green et al. 1986; (26) Lynds \& Wills 1968;
(27) Morris \& Ward 1988; (28) Zotov 1985; (29) Netzer et al. 1994; (30) Barthel et al. 1990;
(31) Ulrich 1976; (32) M ${ }^{\text {c Dowell et al. 1995; (33) Schmidt 1977; }}$
(34) Kimman \& Burbidge 1967; (35) Jauncey et al. 1978

Table 4.2. Emission Line Observations of HST/FOS QSOs

| Name | V | Setup $^{\mathrm{a}}$ | Date | Total exp. time (sec) |
| :--- | :---: | :---: | :---: | :---: |
| $0112-0142$ | 18.0 | 1 | 13Dec1996 | 1200 |
| $0137+0116$ | 17.1 | 1 | 13Dec1996 | 1200 |
| $0232-0415$ | 16.4 | 1 | 13Dec1996 | 1200 |
| $0349-1438$ | 16.2 | 1 | 12Dec1996 | 900 |
| $0414-0601$ | 15.9 | 1 | 19Dec1995 | 400 |
| $0454-2203$ | 16.1 | 1 | 19Dec1995 | 400 |
| $0624+6907$ | 14.2 | 1 | 19Dec1995 | 465 |
| $0827+2421$ | 17.2 | 3 | 15Feb1997 | 1200 |
| $0850+4400$ | 16.4 | 1 | 19Dec1995 | 300 |
| $0859-1403$ | 16.6 | 2a | 12Dec1996 | 3600 |
| $0916+5118$ | 16.5 | 1 | 19Dec1995 | 350 |
| $0923+3915$ | 17.9 | 2b | 14Jan1996 | 1800 |
| $0954+5537$ | 17.7 | 2c | 20Apr1996 | 3600 |
| $0959+6827$ | 16.4 | 2b | 14Jan1996 | 1800 |
| $1001+2910$ | 15.5 | 2a | 12Dec1996 | 3600 |
| $1008+1319$ | 16.2 | 2a | 10Dec1996 | 1800 |
| $1130+1108$ | 16.9 | 2d | 14Jan1996 | 3600 |
| $1138+0204$ | 17.6 | 2e | 12Dec1996 | 2400 |
| $1156+2123$ | 17.5 | 2e | 12Dec1996 | 1800 |
| $1156+2931$ | 17.0 | 2a | 10Dec1996 | 1800 |
| $1214+1804$ | 17.5 | 2f | 21Apr1996 | 1800 |
| $1230+0947$ | 16.1 | 2f | 21Apr1996 | 3600 |
| $1305+0658$ | 17.0 | 2c | 20Apr1996 | 3600 |

Telescope/Instrument set up:
(1) FLWO 1.5 m, FAST, $300 \mathrm{l} \mathrm{mm}^{-1} 1^{\text {st }}$ order, 3 " slit, $3660-7540 \AA$;
(2) SO B90, B\&C, $600 \mathrm{I} \mathrm{mm}^{-1} 1^{\text {st }}$ order, $1.5{ }^{\prime \prime}$ slit,
[a] 4500-6700 $\AA$, [b] 3600-5825 $\AA,[c] 4140-6370 \AA$,
[d] 6870-9140 $\AA$, [e] 5610-7860 $\AA$, [f] 5280-7550 $\AA$;
(3) MMT, Blue Channel, $800 \mathrm{I} \mathrm{mm}^{-1} 1^{\text {st }}$ order, $2^{\prime \prime}$ slit, $4365-6665 \AA$

Table 4.3: Spectrophotometric Properties

| QSO |  | $\overline{\boldsymbol{f}_{\nu_{0}}^{\mathrm{bbs}}}$ <br> (b) | $\begin{gathered} \alpha \\ (\mathrm{c}) \end{gathered}$ | $\overline{f_{\nu_{0}}}$(d) | $\overline{\mathfrak{f}_{\nu}^{0 b s}}$ <br> (e) | $\begin{aligned} & \hline \hline \mathrm{RL} \\ & \text { (f) } \end{aligned}$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | (b) | (c) | (d) | (e) |
| 0003+1553 | 3.88 | 0.46 | $0.71 \pm 0.52$ | $1.39 \pm 0.33$ | 1.94 (1450) | 2.24 | (2) | (1b) | (1b) | (1b) |
| $0003+1955$ | 3.99 | 2.04 | $0.47 \pm 0.09$ | $6.77 \pm 0.45$ | 8.43 (1450) | -0.44 | (3) | (1a) | (1a) | (1a) |
| 0007+1041 | 5.62 |  | $-0.50 \pm 1.00$ | $1.86 \pm 0.66$ | 1.47 (1450) | 0.00 |  | (1a) | (1a) | (1a) |
| $0015+1612$ | 4.07 |  | $-1.14 \pm 0.43$ | $0.19 \pm 0.06$ | 0.11 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 0017+0209 | 3.05 |  | $1.98 \pm 0.56$ | $0.12 \pm 0.08$ | 0.31 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $0024+2225^{1}$ | 3.60 |  | $0.59 \pm 0.65$ | $0.60 \pm 0.15$ | 0.79 (1450) | 2.40 |  | (1c) | (lc) | (1c) |
| 0026+1259 | 4.56 |  | $-0.10 \pm 0.24$ | $2.33 \pm 0.33$ | 2.22 (1450) | -0.04 |  | (1b) | (1b) | (1b) |
| 0042+1010 | 5.52 |  | $0.19 \pm 0.08$ | $0.08 \pm 0.02$ | 0.09 (1450) | 2.99 |  | (1c) | (1c) | (1c) |
| $0043+0354^{1}$ | 3.18 |  | $2.35 \pm 0.04$ | $0.13 \pm 0.01$ | 0.97 (2093) | 0.00 |  | (1c) | (1c) | (1c) |
| $0044+0303$ | 2.88 | 1.16 | $0.34 \pm 0.11$ | $0.67 \pm 0.07$ | 0.79 (1450) | 1.94 | (2) | (1c) | (1c) | (1c) |
| $0050+1225^{1}$ | 1.46 |  | $0.84 \pm 1.14$ | $1.72 \pm 1.05$ | 2.56 (1450) | 0.06 |  | (1a) | (1a) | (1a) |
| 0100+0205 | 2.92 |  | $1.42 \pm 0.27$ | $0.23 \pm 0.06$ | 0.45 (1450) | 0.00 |  | (1b) | (lb) | (1b) |
| 0102-2713 | 1.93 |  |  | 0.18 | 0.29 (1285) | 0.00 |  | (4) |  | (1b) |
| 0107-1537 | 1.73 |  | $0.78 \pm 0.31$ | $0.11 \pm 0.01$ | 0.16 (1450) | 0.00 |  | (1c) | (1c) | (1c) |
| 0112-0142 ${ }^{2}$ | 4.32 |  |  | 0.17 | 0.29 (1326) | 3.83 |  | (4) |  | (1c) |
| $0115+0242^{2}$ | 3.32 |  | $0.83 \pm 0.08$ | $0.05 \pm 0.01$ | 0.08 (1450) | 4.08 |  | (1c) | (1c) | (1c) |
| $0117+2118^{1}$ | 4.75 | 0.39 | $0.15 \pm 40.6$ | $1.77 \pm 7.84$ | 1.88 (1307) | 0.00 | (2) | (1c) | (1c) | (1c) |
| 0121-5903 | 3.05 |  | $0.15 \pm 0.10$ | $2.71 \pm 0.27$ | 2.91 (1450) | 0.00 |  | (la) | (1a) | (1a) |
| 0122-0021 | 3.57 |  | $0.65 \pm 0.07$ | $0.63 \pm 0.07$ | 0.86 (1450) | 3.13 |  | (1c) | (1c) | (1c) |
| 0137+0116 | 3.00 |  | $1.44 \pm 0.31$ | $0.03 \pm 0.02$ | 0.07 (1450) | 3.97 |  | (1b) | (1b) | (1b) |
| 0159-1147 | 1.77 |  | $-0.02 \pm 0.11$ | $1.35 \pm 0.05$ | 1.33 (1450) | 3.01 |  | (1c) | (1c) | (1c) |
| 0214+1050 | 6.96 |  | $1.39 \pm 0.08$ | $0.64 \pm 0.13$ | 1.22 (1450) | 2.57 |  | (1b) | (1b) | (1b) |
| 0232-0415 | 2.42 | 0.59 |  |  |  | 2.73 | (2) |  |  |  |
| 0253-0138 ${ }^{2}$ | 5.61 |  | $0.31 \pm 0.19$ | $0.67 \pm 0.07$ | 0.78 (1450) | 0.00 |  | (1c) | (1c) | (1c) |
| 0254-3327B4 | 2.32 |  | ... | 0.28 | ... | 3.08 |  | (4) |  |  |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\mathrm{N}_{H I}$ $\mathrm{f}_{\nu_{\mathrm{o}}^{\mathrm{bs}}}$ <br> (a) (b) |  | $\begin{gathered} \alpha \\ (\mathrm{c}) \end{gathered}$ | $\begin{aligned} & \hline \mathbf{f}_{\nu_{0}} \\ & (\mathrm{~d}) \\ & \hline \end{aligned}$ | $\overline{f_{\nu}^{p h s}}$ <br> (e) | $\begin{aligned} & \hline \overline{\mathrm{RL}} \\ & (\mathrm{f}) \end{aligned}$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | (b) |  |  |  | (c) | (d) | (e) |
| $0302-2223^{1,4}$ | 1.87 | 0.31 |  | $-2.89 \pm 0.08$ | $2.57 \pm 0.44$ | 0.88 (1318) | 0.00 | (2) | (1c) | (1c) | (1c) |
| 0333+3208 | 13.5 |  | $0.80 \pm 5.79$ | $0.56 \pm 1.65$ | 0.81 (1450) | 3.38 |  | (1c) | (1c) | (1c) |
| 0334-3617 ${ }^{2}$ | 1.40 |  | $0.13 \pm 1.27$ | $0.13 \pm 0.02$ | 0.14 (1450) |  |  | (1c) | (1c) | (lc) |
| 0349-1438 | 3.83 |  | $-0.32 \pm 0.29$ | $2.45 \pm 0.23$ | 2.11 (1450) | 2.53 |  | (1c) | (1c) | (1c) |
| 0355-4820 ${ }^{1}$ | 1.16 | 0.39 | $0.65 \pm 0.58$ | $0.52 \pm 0.13$ | 0.70 (1450) | 2.91 | (5) | (1c) | (1c) | (1c) |
| 0403-1316 ${ }^{2}$ | 3.65 |  | $0.23 \pm 0.04$ | $0.35 \pm 0.05$ | 0.39 (1450) | 4.35 |  | (1c) | (1c) | (1c) |
| 0405-1219 | 3.74 | 2.05 | -0.11 $\pm 0.04$ | $4.38 \pm 0.18$ | 4.14 (1450) | 2.68 | (2) | (1c) | (1c) | (1c) |
| 0414-0601 | 5.14 | 0.34 | $-0.19 \pm 0.08$ | $0.77 \pm 0.05$ | 0.70 (1450) | 2.66 | (2) | (1c) | (1c) | (1c) |
| 0420-0127 ${ }^{3}$ | 7.10 |  | $1.84 \pm 0.05$ | $0.08 \pm 0.01$ | 0.20 (1450) | 3.89 |  | (1c) | (1c) | (1c) |
| 0439-4319 | 2.30 |  | $0.40 \pm 0.08$ | $0.27 \pm 0.01$ | 0.33 (1450) | 2.95 |  | (1c) | (1c) | (1c) |
| $0454+0356^{5}$ | 7.39 | 0.38 | $-0.26 \pm 2.26$ | $1.40 \pm 0.57$ | 1.26 (1336) | 2.50 | (2) | (1c) | (1c) | (1c) |
| 0454-2203 | 2.99 | 0.38 | $0.05 \pm 4.19$ | $1.25 \pm 0.17$ | 1.28 (1450) | 2.77 |  | (1b) | (1b) | (1b) |
| 0518-4549 | 4.12 |  | $0.18 \pm 1.45$ | $0.12 \pm 0.05$ | 0.13 (1450) | 5.06 |  | (1a) | (1a) | (1a) |
| 0537-4406 ${ }^{2}$ | 4.02 | 0.05 | $2.00 \pm 0.16$ | $0.14 \pm 0.03$ | 0.36 (1450) | 4.05 | (2) | (1c) | (1c) | (1c) |
| $0624+6907$ | 7.01 |  | $1.71 \pm 0.03$ | $2.37 \pm 0.18$ | 5.26 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 0637-7513 | 9.22 | 0.53 | $1.32 \pm 0.07$ | $0.27 \pm 0.03$ | 0.49 (1450) | 4.10 | (2) | (1c) | (1c) | (1c) |
| $0710+1151^{2}$ | 11.0 |  | $0.16 \pm 0.08$ | $1.13 \pm 0.10$ | 1.22 (1450) | 4.12 |  | (1c) | (1c) | (lc) |
| $0742+3150^{1}$ | 4.89 | 0.35 | $0.24 \pm 0.43$ | $0.92 \pm 0.08$ | 1.03 (1450) | 2.96 | (2) | (1b) | (1b) | (1b) |
| 0743-6719 | 11.9 | 0.24 |  |  |  | 3.46 | (2) |  |  |  |
| $0827+2421^{3}$ | 3.51 |  | $1.21 \pm 0.04$ | $0.34 \pm 0.03$ | 0.59 (1450) | 3.17 |  | (1c) | (1c) | (1c) |
| $0844+3456^{1}$ | 3.31 |  | $0.75 \pm 0.03$ | $2.31 \pm 0.09$ | 4.94 (2495) | 0.00 |  | (lc) | (1c) | (1c) |
| $0848+1623^{4}$ | 29.7 |  | 0.46 | 0.15 | 0.19 (1450) | 0.00 |  | (6) |  | (11) |
| $0850+4400$ | 2.53 |  | $1.02 \pm 0.20$ | $0.35 \pm 0.05$ | 0.56 (1450) | 0.00 |  | (1b) | (1b) | (lb) |
| 0859-1403 ${ }^{2}$ | 5.71 | 0.60 |  |  |  | 3.29 | (2) |  |  |  |
| $0903+1658^{2}$ | 3.61 |  | $3.28 \pm 0.27$ | $0.03 \pm 0.02$ | 0.17 (1450) | 2.79 |  | (1b) | (1b) | (1b) |
| 0907-0920 ${ }^{6}$ | 4.57 |  | $-0.04 \pm 1.50$ | $0.11 \pm 0.008$ | 0.11 (1822) | 0.00 |  | (1c) | (1c) | (1c) |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\mathrm{N}_{\mathrm{HI}}$ <br> (a) | $\begin{aligned} & \hline \mathrm{f}_{\nu_{0} \mathrm{~s}} \\ & \text { (b) } \\ & \hline \end{aligned}$ | $\alpha$$(\mathrm{c})$ | $\mathrm{f}_{\nu_{0}}$ <br> (d) | $\overline{\mathrm{f}_{\nu}^{\text {obs }}}$ <br> (e) | RL | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | (b) | (c) | (d) | (e) |
| 0916+5118 | 1.40 |  | $0.31 \pm 0.03$ | $0.71 \pm 0.06$ | 0.82 (1450) | 0.00 |  | (1c) | (1c) | (lc) |
| $0923+3915^{2}$ | 1.53 |  | $0.17 \pm 0.05$ | $0.70 \pm 0.03$ | 0.77 (1450) | 4.83 |  | (1c) | (1c) | (1c) |
| $0935+4141^{4,5}$ | 1.32 |  |  | 0.55 |  | 0.00 |  | (4) |  |  |
| $0945+4053$ | 1.44 |  | $-0.33 \pm 5.03$ | $0.17 \pm 0.19$ | 0.15 (1450) | 4.07 |  | (1c) | (1c) | (1c) |
| 0947+3940 | 1.61 |  | $0.70 \pm 0.11$ | $0.90 \pm 0.08$ | 1.25 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 0953+4129 | 1.28 |  | $0.71 \pm 0.08$ | $1.13 \pm 0.10$ | 1.58 (1450) | 0.10 |  | (1b) | (1b) | (1b) |
| $0954+5537^{2}$ | 0.94 |  | $0.96 \pm 0.05$ | $0.12 \pm 0.01$ | 0.18 (1450) | 3.51 |  | (1c) | (1c) | (1c) |
| $0955+3238{ }^{1}$ | 1.62 | 0.38 | $0.96 \pm 0.07$ | $0.45 \pm 0.03$ | 0.87 (1774) | 2.99 | (2) | (1c) | (lc) | (1c) |
| $0958+5509^{1}$ | 0.84 | 0.31 |  |  |  | 0.00 | (2) |  |  |  |
| $0959+6827$ | 3.93 |  | $1.12 \pm 2.21$ | $0.54 \pm 0.71$ | 1.10 (1720) | 1.99 |  | (1c) | (1c) | (1c) |
| $1001+0527^{1}$ | 2.41 |  | $1.73 \pm 0.12$ | $0.24 \pm 0.04$ | 0.55 (1450) | 0.26 |  | (1b) | (1b) | (1b) |
| 1001+2239 | 2.82 |  | $1.67 \pm 0.32$ | $0.05 \pm 0.02$ | 0.12 (1450) | 3.17 |  | (1c) | (1c) | (1c) |
| $1001+2910$ | 1.93 |  | $1.18 \pm 0.02$ | $1.08 \pm 0.06$ | 1.88 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 1007+4147 | 1.23 | 0.72 | $-0.20 \pm 0.08$ | $1.12 \pm 0.07$ | 1.02 (1450) | 2.92 | (2) | (1c) | (1c) | (1c) |
| $1008+1319^{1}$ | 3.79 | 0.58 |  |  |  | 0.00 | (2) |  |  |  |
| $1010+3606$ | 1.24 |  | $0.90 \pm 1.60$ | $0.66 \pm 0.60$ | 1.00 (1450) | 0.00 |  | (1a) | (1a) | (1a) |
| 1026-004A | 4.85 |  |  | 0.11 | 0.19 (1328) | 0.00 |  | (4) |  | (1c) |
| 1026-004B | 4.85 |  |  | 0.15 | 0.24 (1285) | 0.00 |  | (4) |  | (1c) |
| $1038+0625^{1}$ | 2.81 |  | $-0.65 \pm 1.96$ | $1.30 \pm 0.06$ | 1.00 (1361) | 3.09 |  | (1c) | (1c) | (1c) |
| 1049-0035 ${ }^{1}$ | 3.87 | 0.35 | $1.60 \pm 0.11$ | $0.51 \pm 0.07$ | 1.07 (1450) | 0.00 | (2) | (1b) | (1b) | (1b) |
| $1055+2007$ | 1.94 |  | $0.51 \pm 0.37$ | $0.27 \pm 0.05$ | 0.34 (1450) | 3.64 |  | (1c) | (lc) | (lc) |
| $1100+7715^{1}$ | 3.04 |  | $0.67 \pm 0.04$ | $0.97 \pm 0.06$ | 1.33 (1450) | 2.76 |  | (1b) | (1b) | (1b) |
| 1104+1644 | 1.55 |  | $-0.02 \pm 0.15$ | $1.23 \pm 0.08$ | 1.22 (1450) | 2.66 |  | (1c) | (1c) | (lc) |
| $1114+4429^{1}$ | 1.80 |  | $1.80 \pm 0.04$ | $0.15 \pm 0.02$ | 0.35 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $1115+4042^{1}$ | 1.86 |  | $0.44 \pm 0.05$ | $1.10 \pm 0.14$ | 1.35 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 1116+2135 | 1.27 |  | $0.46 \pm 0.10$ | $2.31 \pm 0.36$ | 2.87 (1450) | 0.01 |  | (1b) | (1b) | (b) |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\overline{\mathrm{N}_{H I}}$ <br> (a) | (b) | $\begin{gathered} \alpha \\ (\mathrm{c}) \end{gathered}$ | $\mathrm{f}_{\nu_{0}}$ <br> (d) | $\overline{f_{\nu}^{p b s}}$ <br> (e) | $\begin{aligned} & \hline \text { RL } \\ & \text { (f) } \end{aligned}$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | (b) | (c) | (d) | (e) |
| $1118+1252^{1}$ | 2.28 |  | $0.42 \pm 0.08$ | $0.11 \pm 0.02$ | 0.14 (1450) | 2.75 |  | (1c) | (1c) | (1c) |
| 1127-1432 ${ }^{2}$ | 4.07 |  | $0.96 \pm 3.07$ | $0.31 \pm 0.59$ | 0.49 (1450) | 4.78 |  | (1c) | (1c) | (lc) |
| $1130+1108^{1}$ | 3.47 |  | $1.40 \pm 0.15$ | $0.32 \pm 0.05$ | 0.62 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 1136-1334 | 3.51 | 0.60 | $-0.46 \pm 0.20$ | $1.03 \pm 0.09$ | 0.83 (1450) | 3.36 | (2) | (1b) | (1b) | (1b) |
| $1137+6604^{1}$ | 1.00 | 1.05 | $0.24 \pm 0.04$ | $1.04 \pm 0.09$ | 1.17 (1450) | 2.98 | (2) | (1c) | (1c) | (1c) |
| $1138+0204{ }^{1}$ | 2.37 |  | $0.97 \pm 0.09$ | $0.22 \pm 0.03$ | 0.35 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $1148+5454$ | 1.19 | 0.97 | $0.56 \pm 0.17$ | $1.04 \pm 0.11$ | 1.35 (1450) | -0.13 | (2) | (1c) | (1c) | (1c) |
| $1150+4947$ | 2.01 |  | $0.66 \pm 0.05$ | $0.19 \pm 0.03$ | 0.26 (1450) | 3.44 |  | (1b) | (1b) | (1b) |
| $1156+2123$ | 2.56 |  | $0.95 \pm 0.10$ | $0.31 \pm 0.04$ | 0.49 (1450) | 2.23 |  | (1b) | (1b) | (1b) |
| $1156+2931$ | 1.58 | 0.57 | $1.27 \pm 0.08$ | $0.73 \pm 0.06$ | 1.33 (1450) | 3.04 | (2) | (lc) | (lc) | (l) |
| $1206+4557$ | 1.27 | 0.45 | $-0.32 \pm 0.49$ | $1.96 \pm 0.23$ | 1.69 (1450) | 0.00 | (2) | (1c) | (1c) | (1c) |
| $1211+1419$ | 2.70 |  | $1.27 \pm 0.34$ | $1.31 \pm 0.37$ | 2.37 (1450) | -0.37 |  | (1a) | (1a) | (1a) |
| $1214+1804^{1}$ | 2.74 |  | $1.55 \pm 0.17$ | $0.25 \pm 0.05$ | 0.52 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $1215+6423{ }^{1}$ | 2.10 |  | $-0.14 \pm 2.50$ | $0.19 \pm 0.06$ | 0.18 (1340) | 3.18 |  | (1c) | (1c) | (1c) |
| $1216+0655$ | 1.57 |  | $0.84 \pm 0.06$ | $0.97 \pm 0.06$ | 1.44 (1450) | 0.44 |  | (1b) | (1b) | (1b) |
| $1216+503 \mathrm{a}^{7}$ | 1.87 |  |  | 0.35 | 0.58 (1326) | 0.00 |  | (4) | (1c) | (1c) |
| $1219+0447^{1}$ | 1.68 |  | $0.83 \pm 0.05$ | $0.06 \pm 0.006$ | 0.15 (2457) | 0.00 |  | (1c) | (1c) | (1c) |
| $1219+7535^{2}$ | 3.13 |  | $0.00 \pm 0.36$ | $2.21 \pm 0.34$ | 2.21 (1450) | 0.45 |  | (1a) | (1a) | (1a) |
| $1226+0219^{3}$ | 1.81 | 7.40 | $-1.51 \pm 2.68$ | $47.6 \pm 1.94$ | 26.9 (1330) | 4.26 | (7) | (la) | (1a) | (1a) |
| 1229-0207 ${ }^{5}$ | 2.34 | 0.23 | $1.23 \pm 0.78$ | $0.32 \pm 0.20$ | 0.57 (1450) | 3.25 |  | (1c) | (1c) | (1c) |
| $1230+0947^{2}$ | 1.81 |  | $1.33 \pm 0.36$ | $0.51 \pm 0.16$ | 0.96 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $1241+1737$ | 1.81 | 0.25 | ... |  |  | 2.16 | (2) |  |  |  |
| $1247+2647^{5}$ | 1.03 | 0.76 |  |  |  | -0.07 | (2) |  |  |  |
| $1248+3032$ | 1.23 |  | $0.19 \pm 0.28$ | $0.08 \pm 0.01$ | 0.09 (1450) | 3.19 |  | (1c) | (1c) | (1c) |
| $1248+3142^{8}$ | 1.27 |  |  | 0.26 |  | 0.00 |  | (4) |  | (8) |
| $1248+4007$ | 1.44 | 0.57 | $0.67 \pm 0.76$ | $0.48 \pm 0.16$ | 0.65 (1450) | 0.00 | (2) | (1c) | (1c) | (1c) |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\mathrm{N}_{H I}$ <br> (a) | $f_{\nu_{0}}^{\text {obs }}$ <br> (b) | $\begin{gathered} \alpha \\ (\mathrm{c}) \end{gathered}$ | $\mathrm{f}_{\nu_{0}}$ <br> (d) | $f_{\nu}^{\text {obs }}$ <br> (e) | $\begin{aligned} & \mathrm{RL} \\ & (\mathrm{f}) \end{aligned}$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | (b) | (c) | (d) | (e) |
| $1249+2929^{8}$ | 1.14 |  |  | 0.22 |  | 0.00 |  | (4) |  | (8) |
| $1250+3122$ | 1.24 |  |  | 0.33 | 0.54 (1279) | 0.00 |  | (4) | (1b) | (1b) |
| $1252+1157$ | 2.34 |  | $0.80 \pm 0.38$ | $0.37 \pm 0.07$ | 0.54 (1450) | 3.12 |  | (1c) | (1c) | (1c) |
| 1253-0531 ${ }^{2}$ | 2.12 | 1.43 | $1.58 \pm 0.02$ | $0.14 \pm 0.01$ | 0.30 (1450) | 4.47 | (2) | (1c) | (1c) | (1c) |
| $1257+3439^{1}$ | 1.13 |  |  | 0.51 | 0.94 (1450) | 1.14 |  | (4) |  | (9) |
| $1258+2835{ }^{1}$ | 0.93 |  | $0.21 \pm 0.81$ | $0.32 \pm 0.04$ | 0.34 (1331) | 0.00 |  | (1c) | (1c) | (1c) |
| $1259+5918$ | 1.37 | 1.02 | $1.14 \pm 0.45$ | $0.96 \pm 0.32$ | 1.63 (1450) | 0.00 | (2) | (1b) | (1b) | (1b) |
| 1302-1017 | 3.37 | 0.99 | $1.17 \pm 0.06$ | $2.00 \pm 0.14$ | 3.47 (1450) | 2.34 | (2) | (1b) | (1b) | (1b) |
| $1305+0658$ | 2.16 |  | $-0.07 \pm 0.04$ | $0.24 \pm 0.03$ | 0.23 (1450) | 3.13 |  | (1c) | (1c) | (1c) |
| $1309+3531^{1}$ | 2.55 |  | $1.08 \pm 0.16$ | $0.68 \pm 0.11$ | 1.12 (1450) | 1.58 |  | (1b) | (lb) | (1b) |
| $1317+2743$ | 1.18 | 0.73 | $0.64 \pm 0.19$ | $1.04 \pm 0.10$ | 1.40 (1450) | 0.00 | (2) | (1c) | (1c) | (lc) |
| $1317+5203^{1,2}$ | 1.90 |  | $0.54 \pm 0.82$ | $0.51 \pm 0.15$ | 0.66 (1450) | 2.70 |  | (1c) | (1c) | (lc) |
| $1318+2903$ | 1.14 | 0.26 | $-0.06 \pm 10.0$ | $0.58 \pm 0.25$ | 0.56 (1450) | 0.00 | (2) | (1b) | (lb) | (1b) |
| $1320+2925$ | 1.17 |  | $1.37 \pm 1.63$ | $0.19 \pm 0.26$ | 0.36 (1450) | 0.00 |  | (1c) | (1c) | (lc) |
| $1322+6557$ | 1.92 |  | $0.91 \pm 0.16$ | $0.66 \pm 0.07$ | 1.01 (1450) | 0.00 |  | (1b) | (1b) | (lb) |
| $1323+6530^{1,4,5}$ | 1.99 |  |  | 0.11 |  | 3.02 |  | (4) |  |  |
| 1327-2040 ${ }^{1}$ | 7.53 | 0.19 | $0.83 \pm 0.41$ | $0.55 \pm 0.12$ | 0.82 (1450) | 2.62 | (2) | (1c) | (1c) | (1c) |
| $1328+3045^{5}$ | 1.16 |  | $0.39 \pm 0.13$ | $0.20 \pm 0.01$ | 0.24 (1450) | 4.49 |  | (1c) | (1c) | (1c) |
| $1329+4117^{5}$ | 0.97 | 0.95 |  |  |  | 0.00 | (2) |  |  |  |
| $1333+1740$ | 1.75 | 0.51 | $0.92 \pm 4.71$ | $0.65 \pm 1.81$ | 1.01 (1450) | 1.39 | (2) | (1b) | (1b) | (1b) |
| $1351+3153^{1,5}$ | 1.29 |  | $-0.91 \pm 2.78$ | $0.16 \pm 0.28$ | 0.11 (1319) | 2.88 |  | (1c) | (1c) | (1c) |
| $1351+6400^{1}$ | 2.10 |  | $0.97 \pm 0.06$ | $1.62 \pm 0.07$ | 4.36 (2531) | 1.10 |  | (1c) | (1c) | (1c) |
| $1352+0106$ | 2.25 | 0.07 | $0.50 \pm 1.23$ | $0.83 \pm 0.33$ | 1.05 (1450) | 0.00 | (2) | (1c) | (1c) | (1c) |
| $1352+1819$ | 2.03 |  | $0.38 \pm 0.13$ | $0.59 \pm 0.11$ | 0.71 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $1354+1933$ | 2.21 | 0.40 | $0.68 \pm 0.11$ | 0.56 $\pm 0.05$ | 0.77 (1450) | 3.53 | (2) | (1c) | (1c) | (1c) |
| $1356+5806^{2}$ | 1.40 |  | $0.09 \pm 6.29$ | $0.56 \pm 0.04$ | 0.59 (1344) | 2.34 |  | (1c) | (1c) | (1c) |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\mathrm{N}_{\text {III }}$ <br> (a) | ${ }^{\prime \prime} \mathrm{f}_{\nu_{0}}^{\mathrm{bbs}}$ <br> (b) | $\begin{gathered} \hline \alpha \\ (\mathrm{c}) \end{gathered}$ | $\mathrm{f}_{\nu_{0}}$ <br> (d) | $\overline{f_{\nu}^{\text {obs }}}$ <br> (e) | $\begin{aligned} & \hline \mathrm{RL} \\ & (\mathrm{f}) \end{aligned}$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | (b) | (c) | (d) | (e) |
| $1401+0952^{2}$ | 1.96 |  | $2.03 \pm 0.29$ | $0.12 \pm 0.05$ | 0.31 (1450) | 0.72 |  | (1b) | (1b) | (1b) |
| $1404+2238{ }^{1}$ | 1.99 |  | $1.03 \pm 0.04$ | $0.31 \pm 0.04$ | 0.86 (2413) | 0.29 |  | (1c) | (lc) | (lc) |
| $1407+2632$ | 1.47 | 0.83 | $0.28 \pm 0.05$ | $1.20 \pm 0.07$ | 1.38 (1450) | 0.00 | (2) | (1c) | (1c) | (1c) |
| $1415+4509$ | 1.13 |  | $0.65 \pm 0.08$ | $0.85 \pm 0.05$ | 1.32 (1790) | 0.00 |  | (1b) | (1b) | (1b) |
| $1416+0642^{1}$ | 6.24 |  | $1.20 \pm 15.9$ | $0.25 \pm 3.47$ | 0.40 (1308) | 3.67 |  | (1c) | (1c) | (lc) |
| 1424-1150 | 7.54 |  | $-0.04 \pm 0.18$ | $0.85 \pm 0.07$ | 0.83 (1450) | 2.59 |  | (lc) | (1c) | (lc) |
| $1425+2645^{1}$ | 2.55 | 0.15 | $1.67 \pm 0.10$ | $0.22 \pm 0.03$ | 0.48 (1450) | 2.43 | (2) | (1b) | (1b) | (1b) |
| $1427+4800$ | 1.88 |  | $0.47 \pm 0.24$ | $0.69 \pm 0.07$ | 0.86 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| 1435-0134 | 3.66 | 0.82 |  |  |  | 0.00 | (5) |  |  |  |
| $1440+3539^{1}$ | 1.00 |  | $0.44 \pm 0.09$ | $3.61 \pm 0.15$ | 4.96 (1857) | -0.58 |  | (1b) | (1b) | (1b) |
| $1444+4047$ | 1.27 | 0.89 | $0.86 \pm 0.04$ | $1.06 \pm 0.06$ | 1.59 (1450) | 0.00 | (2) | (1b) | (1b) | (1b) |
| $1512+3701$ | 1.39 | 0.57 | $0.94 \pm 0.12$ | $0.61 \pm 0.06$ | 0.95 (1450) | 2.75 | (2) | (1b) | (1b) | (1b) |
| $1517+2356^{4}$ | 3.91 |  |  | 0.51 |  | 0.00 |  | (4) |  |  |
| $1517+2357^{4}$ | 3.91 |  |  | 0.08 |  | 0.00 |  | (4) |  |  |
| $1521+1009$ | 2.88 | 1.65 |  |  |  | 0.00 | (2) |  |  |  |
| $1538+4745^{1}$ | 1.64 | 0.34 | $0.57 \pm 0.06$ | $1.03 \pm 0.05$ | 1.34 (1450) | 1.28 | (2) | (1c) | (1c) | (1c) |
| $1544+4855$ | 1.60 | 0.10 | $2.04 \pm 1.72$ | $0.36 \pm 0.81$ | 0.95 (1450) | 0.00 | (2) | (1b) | (1b) | (1b) |
| $1555+3313^{2}$ | 2.35 |  | $1.79 \pm 0.08$ | $0.03 \pm 0.005$ | 0.07 (1450) | 3.03 |  | (1c) | (1c) | (1c) |
| $1611+3420^{2}$ | 1.65 |  |  | 0.18 | 0.30 (1322) | 4.88 |  | (4) | (1c) | (1c) |
| $1618+1743$ | 4.14 |  | $-0.30 \pm 0.05$ | $1.30 \pm 0.06$ | 1.13 (1450) | 2.70 |  | (1b) | (1b) | (1b) |
| $1622+2352$ | 4.46 |  | $1.75 \pm 0.16$ | $0.09 \pm 0.01$ | 0.21 (1450) | 3.54 |  | (1c) | (1c) | (lc) |
| $1626+5529^{1}$ | 1.83 |  | $0.29 \pm 0.16$ | $1.13 \pm 0.22$ | 1.30 (1450) | 0.00 |  | (1b) | (1b) | (1b) |
| $1630+3744$ | 1.07 | 0.84 |  |  |  | 0.00 | (2) |  |  |  |
| $1634+7037$ | 4.55 | 1.96 |  |  |  | 0.00 | (2) |  |  |  |
| $1637+5726^{2}$ | 1.90 |  | $0.17 \pm 0.02$ | $0.64 \pm 0.05$ | 0.70 (1450) | 3.98 |  | (1c) | (1c) | (1c) |
| $1641+3954^{3}$ | 1.02 | 0.61 | $1.04 \pm 0.08$ | $0.41 \pm 0.06$ | 0.67 (1450) | 3.92 | (2) | (1c) | (1c) | (1c) |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\overline{\overline{\mathbf{N}_{H I}}}$ <br> (a) | $\overline{\boldsymbol{f}_{\nu_{0}}^{\mathrm{obs}}}$ <br> (b) | $\alpha$ <br> (c) | $\begin{aligned} & \hline \mathbf{f}_{\nu_{0}} \\ & \text { (d) } \\ & \hline \end{aligned}$ | $\overline{\mathbf{f}_{\nu}^{\text {obs }}}$ <br> (e) | $\begin{aligned} & \mathrm{RL} \\ & (\mathrm{f}) \end{aligned}$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | (b) | (c) | (d) | (e) |
| $1704+6048^{1}$ | 2.32 | 0.90 | $1.25 \pm 0.16$ | $0.94 \pm 0.14$ | 1.68 (1450) | 2.86 | (2) | (1b) | (1b) | (1b) |
| $1715+5331$ | 2.71 |  | 0.43 | 0.58 | 0.29 (1450) | 0.53 |  | (10) |  | (2) |
| $1718+4807^{1}$ | 2.27 |  | $-0.43 \pm 0.84$ | $5.01 \pm 1.16$ | 4.09 (1450) | 1.52 |  | (1c) | (1c) | (1c) |
| $1803+7827^{3}$ | 3.92 |  | $1.69 \pm 0.02$ | $0.53 \pm 0.05$ | 1.16 (1450) | 3.35 |  | (1c) | (1c) | (1c) |
| $1821+6419^{1}$ | 3.98 | 1.86 | $0.86 \pm 0.07$ | $3.90 \pm 0.13$ | 8.37 (2204) | 1.10 | (2) | (1c) | (1c) | (1c) |
| $1845+7943^{1}$ | 4.17 |  | $0.66 \pm 0.27$ | $0.42 \pm 0.08$ | 0.58 (1450) | 3.88 |  | (1a) | (1a) | (1a) |
| $2112+0556$ | 6.48 | 0.29 | $0.48 \pm 0.93$ | $0.54 \pm 0.16$ | 0.67 (1450) | 0.00 | (2) | (1b) | (1b) | (1b) |
| 2128-1220 | 4.75 | 0.35 | $0.27 \pm 1.63$ | $1.77 \pm 0.51$ | 2.02 (1450) | 2.99 | (11) | (1b) | (1b) | (1b) |
| 2135-1446 ${ }^{1}$ | 4.71 |  | $0.94 \pm 0.42$ | $0.57 \pm 0.15$ | 0.88 (1450) | 3.17 |  | (1b) | (1b) | (1b) |
| $2141+1730{ }^{1}$ | 8.20 |  | $1.22 \pm 0.05$ | $0.81 \pm 0.14$ | 1.43 (1450) | 2.84 |  | (1b) | (lb) | (1b) |
| $2145+0643$ | 4.90 |  | $0.99 \pm 0.68$ | $0.72 \pm 0.31$ | 1.14 (1450) | 3.58 |  | (1c) | (1c) | (1c) |
| $2201+3131^{2}$ | 9.02 | 0.60 | $0.96 \pm 0.08$ | $3.15 \pm 0.33$ | 4.93 (1450) | 3.64 | (2) | (1b) | (1b) | (1b) |
| 2216-0350 ${ }^{2}$ | 5.66 | 0.18 | $1.21 \pm 0.09$ | $0.40 \pm 0.05$ | 0.71 (1450) | 3.43 | (2) | (1c) | (1c) | (1c) |
| 2223-0512 ${ }^{2}$ | 5.47 | 0.16 |  |  |  | 4.35 | (2) |  |  |  |
| $2230+1128^{2}$ | 5.42 |  | $0.76 \pm 0.96$ | $0.45 \pm 0.21$ | 0.64 (1450) | 4.39 |  | (1c) | (1c) | (1c) |
| 2243-1222 | 4.94 |  | $-0.38 \pm 0.06$ | $1.50 \pm 0.10$ | 1.25 (1450) | 3.32 |  | (1c) | (1c) | (1c) |
| $2251+1120^{1}$ | 5.08 |  | 1.2 | 1.46 | 0.49 (1450) | 3.06 |  | (12) |  | (2) |
| $2251+1552$ | 6.38 | 0.09 | $1.04 \pm 0.05$ | $0.71 \pm 0.07$ | 1.15 (1450) | 3.94 | (2) | (1c) | (lc) | (1c) |
| 2251-1750 ${ }^{\text {1 }}$ | 2.77 |  | $1.06 \pm 0.08$ | $1.47 \pm 0.09$ | 4.32 (2507) | 0.07 |  | (1c) | (1c) | (1c) |
| 2300-6823 | 3.69 |  | $-0.34 \pm 0.75$ | $0.26 \pm 0.04$ | 0.22 (1450) | 3.18 |  | (1b) | (1b) | (1b) |
| 2340-0339 | 3.61 |  | $0.68 \pm 0.05$ | $0.99 \pm 0.06$ | 1.36 (1450) | 2.24 |  | (1c) | (lc) | (1c) |
| $2344+0914$ | 5.76 | 0.34 |  | 0.22 | 0.41 (1450) | 3.52 | (2) | (4) | (9) | (9) |
| 2352-3414 | 1.08 |  | $0.07 \pm 0.03$ | $0.74 \pm 0.05$ | 0.77 (1450) | 2.70 |  | (1c) | (1c) | (1c) |

Table 4.3: Spectrophotometric Properties (Continued)

| QSO | $\mathrm{N}_{H I}$ $\mathrm{f}_{\nu 0}^{\mathrm{obs}}$ <br> (a) (b) |  | $\begin{gathered} \alpha \\ (\mathrm{c}) \end{gathered}$ | $\begin{aligned} & \hline \mathrm{f}_{\nu_{0}} \\ & \text { (d) } \end{aligned}$ | $\overline{\mathrm{f}_{\nu}^{\mathrm{obs}}}$(e) | $\overline{\mathrm{RL}}$$(f)$ | References |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | (b) |  |  |  | (c) | (d) | (e) |

(a) $10^{20} \mathrm{~cm}^{-2}$ from Stark et al. 1992; Burstein \& Heiles 1982; Lockman \& Dickey 1995;
(b) Direct measurement of flux at Lyman Limit in $\mu \mathrm{J} y$;
(c) Measured spectral index;
(d) Extrapolated flux at Lyman Limit in $\mu \mathrm{Jy}$;
(e) Measured flux at the rest wavelength listed in $\AA$;
(f) Radio Loudness, $\mathrm{RL}=\log [\mathrm{S}(5 \mathrm{GHz})] / \log [\mathrm{S}(1450 \AA)]$
${ }^{1}$ Object spectrum shows associated absorption
${ }^{2}$ Observed only with pre-COSTAR FOS and A-1 aperture, not used for proximity effect
${ }^{3}$ Object is classified as a blazar or BL Lac
${ }^{4}$ Flux estimated from scaling composite QSO spectrum to match V
${ }^{5}$ Object spectrum shows damped Ly- $\alpha$ absorption
${ }^{6}$ No Ly- $\alpha$ forest observed, not used for proximity effect
${ }^{7}$ Binary quasar, not used for proximity effect
${ }^{8}$ Flux estimated from scaling composite QSO spectrum to match B References:
(1) this paper, FOS data [a] H130, [b] H190, [c] H270; (2) Lanzetta et al. 1993;
(3) Zheng et al. 1995; (4) Zheng et al. 1997; (5) Hamann et al. 1995; (6) Tytler \& Fan 1992
(7) Appenzeller et al. 1998; (8) Sanduleak \& Pesch 1984; (9) Osmer et al. 1994;
(10) Zheng \& Malkan 1993; (11) Kinney et al. 1991; (12) Green 1996

Table 4.4: Measurements of $J\left(\nu_{0}\right)$

| Sample <br> (a) | $\mathcal{N}_{\text {lines }}$ <br> (b) | $\gamma$,norm. <br> (c) | $\beta$ | $\begin{gathered} \hline \mathrm{b} \\ (\mathrm{~d}) \end{gathered}$ | method <br> (e) | $\left.\overline{\log [J}\left(\nu_{0}\right)\right]$ <br> (f) | $\begin{aligned} & \hline \chi^{2} \\ & \text { (g) } \end{aligned}$ | $\overline{\mathrm{Q}_{\mathrm{X}^{2}}}$ <br> (h) | QKS <br> (i) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1. | 259 | 0.82, 13.6 | 1.46 |  | BDO | -22.04-1.41 | 2.13 | 0.95 | 0.80 |
| 1. | 259 | 0.82, 6.73 | 1.46 | 35 | ML | -22.11 ${ }_{-0.40}^{+0.51}$ | 1.21 | 0.29 | 0.80 |
| 1 | 259 | 0.82, 9.61 | 1.46 | 25 | ML | -22.12 ${ }_{-0.39}^{+0.52}$ | 1.01 | 0.41 | 0.80 |
| 1. | 259 | 0.82, 9.31 | 1.45 | 25 | ML | -22.13-0.41 | 0.78 | 0.58 | 0.80 |
| 1. | 259 | 0.82, 11.8 | 1.70 | 30 | ML | $-21.74_{-0.36}^{+0.45}$ | 1.34 | 0.23 | 0.80 |
| 1 | 259 | 0.82, 38.0 | 2.04 | 25 | ML | $-21.47_{-0.32}^{+0.43}$ | 1.10 | 0.35 | 0.80 |
| 2. | 289 | 0.15, 31.3 | 1.46 |  | BDO | $-22.06_{-0.62}^{+0.05}$ | 2.62 | 0.91 | 0.30 |
| 2. | 289 | $0.15,12.0$ | 1.46 | 35 | ML | $-22.03_{-0.37}^{+0.44}$ | 1.32 | 0.24 | 0.30 |
| 2. | 289 | 0.15, 13.9 | 1.46 | 25 | ML | -22.04 ${ }_{-0.36}^{+0.45}$ | 1.34 | 0.23 | 0.30 |
| 2. | 289 | $0.15,13.6$ | 1.45 | 25 | ML | $-22.06_{-0.37}^{+0.45}$ | 1.48 | 0.18 | 0.30 |
| 2 | 289 | $0.15,17.6$ | 1.70 | 30 | ML | $-21.69_{-0.32}^{+0.40}$ | 1.47 | 0.18 | 0.30 |
| 2. | 289 | 0.15, 31.1 | 2.04 | 25 | ML | $-21.42_{-0.28}^{+0.37}$ | 0.88 | 0.50 | 0.30 |
| 1 a | 162 | 1.50, 10.1 | 1.46 |  | BDO | $-22.87_{-0.82}^{+1.19}$ | 1.51 | 0.98 | 0.64 |
| 1a | 162 | 1.50, 4.92 | 1.46 | 35 | ML | $-22.18_{-0.61}^{+0.90}$ | 0.17 | 0.98 | 0.64 |
| 1a | 162 | 1.50, 3.67 | 1.46 | 35 | ML | $-21.72_{-0.74}^{+1.521}$ | 1.02 | 0.40 | 0.62 |
| 1 a | 162 | 1.50, 3.71 | 1.46 | 35 | ML | $-21.88_{-0.73}^{+1.542}$ | 0.98 | 0.43 | 0.62 |
| 1 b | 97 | -0.87, 53.0 | 1.46 |  | BDO | $-22.02_{-1.33}^{+0.005}$ | 2.44 | 0.87 | 0.98 |
| 1 b | 97 | -0.87, 26.1 | 1.46 | 35 | ML | $-21.98_{-0.54}^{+0.76}$ | 2.25 | 0.03 | 0.98 |
| 1b | 97 | -0.87, 21.5 | 1.46 | 35 | ML | -21.76 ${ }_{-0.58}^{+0.921}$ | 1.31 | 0.24 | 0.95 |
| 1b | 97 | -0.87, 21.5 | 1.46 | 35 | ML | $-21.95_{-0.57}^{+0.932}$ | 1.27 | 0.26 | 0.95 |
| 3. | 214 | 0.28, 9.97 | 1.46 | 35 | ML | $-21.57_{-0.52}^{+0.80}$ | 0.47 | 0.82 | 0.70 |
| 4. | 208 | 1.04, 5.76 | 1.46 | 35 | ML | $-22.15_{-0.46}^{+0.66}$ | 1.47 | 0.19 | 0.65 |
| 5. | 373 | 0.60, 7.93 | 1.46 | 35 | ML | $-21.74_{-0.39}^{+0.45}$ | 0.97 | 0.44 | 0.96 |
| 6. | 301 | 0.89, 6.57 | 1.46 | 35 | ML | -22.17 ${ }_{-0.37}^{+0.44}$ | 0.98 | 0.43 | 0.97 |
| 7..... | 415 | 0.67, 7.72 | 1.46 | 35 | ML | $-21.82_{-0.37}^{+0.46}$ | 0.93 | 0.46 | 0.98 |

Table 4.4: Measurements of $J\left(\nu_{0}\right)$ (Continued)

| Sample <br> (a) | $\overline{\mathcal{N}_{\text {lines }}}$ (b) | $\gamma$,norm. <br> (c) | $\beta$ | b <br> (d) | method <br> (e) | $\log \left[J\left(\nu_{0}\right)\right]$ <br> (f) | $\begin{aligned} & \hline \chi^{2} \\ & (\mathrm{~g}) \end{aligned}$ | $\overline{\mathrm{Q}_{\chi^{2}}}$ <br> (h) | QKS <br> (i) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 7 a | 213 | 0.79, 7.28 | 1.46 | 35 | ML | -22.22 ${ }_{-0.51}^{+0.74}$ | 0.29 | 0.94 | 0.64 |
| 7b | 202 | 0.72, 7.29 | 1.46 | 35 | ML | -21.60 ${ }_{-0.47}^{+0.70}$ | 1.15 | 0.33 | 0.98 |
| 8. | 422 | 0.69, 7.64 | 1.46 | 35 | ML | $-21.85{ }_{-0.36}^{+0.46}$ | 0.82 | 0.55 | 0.97 |
| 8 a | 220 | 0.84, 7.10 | 1.46 | 35 | ML | $-22.23_{-0.49}^{+0.73}$ | 0.46 | 0.83 | 0.56 |
| 8b | 202 | 0.72, 7.29 | 1.46 | 35 | ML | -21.60-0.47 | 1.15 | 0.33 | 0.98 |
| 9. | 906 | 0.61, 9.26 | 1.46 | 35 | ML | -21.21 ${ }_{-0.32}^{+0.49}$ | 0.55 | 0.76 | 0.91 |
| 9a | 474 | 0.63, 9.23 | 1.46 | 35 | ML | $-21.79_{-0.40}^{+0.53}$ | 0.76 | 0.59 | 0.87 |
| 9b.... | 432 | $1.05,6.40$ | 1.46 | 35 | ML | $-20.82_{-0.51}^{+\infty}$ | 0.33 | 0.91 | 0.71 |

(a) Sample number-
(1) all lines with $W>0.32 \AA$, (1a) $z<1$, (1b) $z>1$;
(2) all lines with $W>0.24 \AA$, (2a) $z<1$, (2b) $z>1$;
(3) RL $>1.0$; (4) RL $<1.0$;
(5) sample (1) including associated absorbers;
(6) sample (1) including damped Ly- $\alpha$ absorbers;
(7) sample (1) including both associated absorbers and damped Ly- $\alpha$ absorbers;
(7a) $z<1$, (7b) $z>1$;
(8) sample (1) including associated absorbers, damped Ly- $\alpha$ absorbers, and blazars;
(8a) $z<1$, (8b) $z>1$;
(9) sample (8), all lines above variable threshold, (9a) $z<1$, (9b) $z>1$

Table 4.5. Simulation Results

| Input $\log \left[J\left(\nu_{0}\right)\right]$ <br> $(\mathrm{a})$ | $z$ <br> $(\mathrm{~b})$ | $W_{\text {thr }}$ <br> $(\mathrm{c})$ | $\gamma, A$ <br> $(\mathrm{~d})$ | Recovered $\log \left[J\left(\nu_{0}\right)\right]$ <br> $(\mathrm{e})$ | $\chi^{2}$ <br> $(\mathrm{f})$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| -23.0 | all | 0.32 | $1.41,7.81$ | $-22.74_{-0.13}^{+0.15}$ | 5.13 |
| -23.0 | all | variable | $1.15,8.94$ | $-22.47_{-0.12}^{+0.13}$ | 5.73 |
| -22.0 | all | 0.32 | $1.17,8.27$ | $-21.32_{-0.29}^{+0.41}$ | 13.6 |
| -22.0 | $z<1$ | 0.32 | $0.95,8.74$ | $-20.81_{-0.62}^{+1.91}$ | 9.53 |
| -22.0 | $z>1$ | 0.32 | $1.79,5.21$ | $-21.64_{-0.28}^{+3.39}$ | 6.70 |
| -22.0 | all | variable | $1.48,6.71$ | $-21.63_{-0.19}^{+0.20}$ | 3.21 |
| -22.0 | $z<1$ | variable | $0.75,10.0$ | $-21.34_{-0.36}^{+0.60}$ | 11.3 |
| -22.0 | $z>1$ | variable | $1.52,6.09$ | $-21.63_{-0.22}^{+0.25}$ | 1.30 |
| -21.0 | all | 0.32 | $1.44,7.25$ | $-20.81_{-0.41}^{+0.65}$ | 1.56 |
| -21.0 | all | variable | $1.13,8.72$ | $-20.81_{-0.38}^{+0.53}$ | 0.73 |
| $(0.017) \log (1+z)-21.87$ | all | 0.32 | $0.99,9.46$ | $-21.54_{-0.25}^{+3.38}$ | 3.35 |
| $(0.017) \log (1+z)-21.87$ | $z<1$ | 0.32 | $0.51,11.1$ | $-21.80_{-0.45}^{+0.80}$ | 4.63 |
| (0.017) $\log (1+z)-21.87$ | $z>1$ | 0.32 | $1.90,4.74$ | $-21.54_{-0.29}^{+0.40}$ | 1.55 |
| $(0.017) \log (1+z)-21.87$ | all | variable | $1.38,7.32$ | $-21.56_{-0.21}^{+0.22}$ | 0.57 |
| $(0.017) \log (1+z)-21.87$ | $z<1$ | variable | $0.84,10.1$ | $-21.83_{-0.34}^{+0.45}$ | 3.28 |
| $(0.017) \log (1+z)-21.87$ | $z>1$ | variable | $2.48,2.67$ | $-21.37_{-0.23}^{+0.31}$ | 0.82 |

(a) Value of $\log \left[J\left(\nu_{0}\right)\right]$ used for modifying absorber column densities according to Equ. 4.4 and Equ. 4.4;
(b) Redshift range of solution;
(c) Equivalent width threshold in $\AA$ for line sample used in solution;
(d) Maximum likelihood $\gamma$ for line sample used, maximum likelihood method normalization, see $\S 4.5$, Equ. 4.10;
(e) Value of $\log \left[J\left(\nu_{0}\right)\right]$ from simulated spectra using the ML technique;
(f) $\chi^{2}$ of data versus the BDO ionization model

Table 4.6. HI Ionization Rates

| Sample <br> (a) | $\gamma, A$ <br> (b) | $\beta$ | b | $\log \left[\Gamma_{\mathrm{HI}}\right]$ | $\begin{aligned} & \hline \chi_{\nu}^{2} \\ & (\mathrm{c}) \end{aligned}$ | $Q_{\chi_{\nu}^{2}}$ <br> (d) | $\overline{\log \left[J\left(\nu_{0}\right)\right]}$ <br> (e) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1. | 0.69,7.65 | 1.46 | 35 | $-12.17_{-0.40}^{+0.50}$ | 0.49 | 0.81 | -21.56 |
| 1 a | 0.85,7.11 | 1.46 | 35 | $-12.70_{-0.51}^{+0.74}$ | 0.38 | 0.88 | -22.09 |
| 1b | 0.72,7.29 | 1.46 | 35 | $-11.88_{-0.50}^{+0.74}$ | 0.48 | 0.81 | -21.28 |
| 2. | 0.61,9.27 | 1.46 | 35 | $-11.27_{-0.45}^{+0.74}$ | 0.78 | 0.58 | -20.67 |
| 2a | 0.63,9.24 | 1.46 | 35 | $-12.23_{-0.42}^{+0.55}$ | 1.17 | 0.31 | -21.62 |
| 2b | 1.05,6.40 | 1.46 | 35 | $-9.089_{-2.22}^{+\infty}$ | 1.17 | 0.31 | -18.48 |
| 1. | 0.69, $7.21{ }^{1}$ | 1.46 | 35 | $-12.67,1.73^{1}$ | 1.01 | 0.40 |  |
| 2..... | 0.61, $9.04{ }^{1}$ | 1.46 | 35 | -10.86,3.04 | 0.47 | 0.82 | $\ldots$ |

(2) all lines above variable threshold, (2a) $z<1$, (2b) $z>1$;
(b) Maximum likelihood method normalization (see §4.5, Equ. 4.10);
(c) $\chi^{2}$ of data versus the ionization model used;
(d) $\chi^{2}$ probability for the ionization model used;
(e) $J\left(\nu_{0}\right)$ implied by $\Gamma$ listed and $\alpha_{s}=1.8$ (see $\S 4.5 .2$, Equ. 4.12)
${ }^{1}$ maximum likelihood solution for $\log \left(A_{\mathrm{pl}}\right), B_{\mathrm{pl}}$ and normalization (see §4.5.2, Equ. 4.13)


Figure 4.1. Histograms of (a) QSO redshifts in proximity effect sample, dotted line indicates objects classified as blazars or BL Lacs, and (b) Ly- $\alpha$ line redshifts in proximity effect sample, (solid line)- lines above variable threshold, (dashed line)lines with $W>0.32 \AA$ (dotted line)- lines with $W>0.24 \hat{A}$


Figure 4.2. Emission line spectra of sample QSOs used to measure redshifts


Figure 4.2. Emission line spectra of HST/FOS QSOs (Continued)


Figure 4.2. Emission line spectra of HST/FOS QSOs (Continued)


Figure 4.2. Emission line spectra of HST/FOS QSOs (Continued)


Figure 4.3. Histograms of redshift differences between [OIII] and (a) $\mathrm{Ly}-\alpha$, (b) Mg II, and (c) Balmer emission lines, dotted lines show results from Laor et al. (1995)


Figure 4.4. FOS spectra used to extrapolate to the Lyman limit flux of each object: (dashed lines) power law fits, (dotted lines) $1 \sigma$ errors in spectrum


Figure 4.5. Lyman limit luminosity versus redshift for objects in the HST/FOS sample (squares) and in the MMT sample presented in Papers I and II (crosses), solid line indicates the boundary between low and high luminosity objects


Figure 4.6. (a) Relative deficit of lines with respect to the number predicted by Equ. 4.1 for $W_{t h r}=0.32 \AA$ versus distance from the QSO for high and low luminosity QSOs (thick and thin solid lines, respectively) in both the HST/FOS sample presented in Paper III and the MMT sample presented in Paper I; (b) Deficit of lines within 2 $\mathrm{h}_{75}^{-1} \mathrm{Mpc}$ as a function of QSO Lyman limit luminosity for the HST/FOS and MMT samples, the vertical line delineates the boundary between low and high luminosity objects


Figure 4.7. $\chi^{2}$ of binned data with respect to the ionization model expressed in Equ. 4.11 versus $\log \left[J\left(\nu_{0}\right)\right]$ for various redshift ranges and equivalent width thresholds: (a) $W_{t h r}=0.32 \dot{A}$; (b) $W_{t h r}=0.32 \AA, z<1$; (c) $W_{t h r}=0.32 A, z>1$; (d) $W_{t h r}=0.24 \hat{A}$


Figure 4.8. Number distribution per coevolving redshift coordinate expressed in Equ. 4.11 for the best fit values of $J\left(\nu_{0}\right)$ (BDO method); (a-d) same as Fig. 4.7


Figure 4.9. Likelihood function versus $\log \left[J\left(\nu_{0}\right)\right]$ for $W_{\text {thr }}=0.32 \AA(\beta, b)=(\mathrm{a})$ (1.46,35); (b) $(1.46,25)$; (c) $(1.45,25)$; (d) $(1.70,30)$; (e) $(2.04,25)$; (f) $(1.46,35), z<1$; (g) $(1.46,35), z>1$; and for $W_{t h r}=0.24 \hat{A}(\beta, b)=(\mathrm{h})(1.46,35)$; (i) $(1.46,25)$; (j) $(1.45,25)$; (k) $(1.70,30)$; (l) $(2.04,25)$


Figure 4.10. Number distribution per coevolving redshift coordinate for the best fit values of $J\left(\nu_{0}\right)$ (KF method); (a-l) same as Fig. 4.9; the dotted point and error bars in (g) has been divided by 5 for clarity


Figure 4.11. $\log \left[J\left(\nu_{0}\right)\right]$ versus redshift, solid curves in (a)-(f) correspond to HM96 models: (a) $W_{\text {thr }}=0.32 \AA$ all redshifts, $0.03<z<1.67$, and $z<1, z>1$ separately, ML method; (b) same as (a), BDO method; (c) variable threshold, all redshifts $0.03<z<1.67$, and $z<1, z>1$ separately; (d) $W_{\text {thr }}=0.32 \AA$ all redshifts, $\mathrm{RL}>0.3$ and $\mathrm{RL}<0.3$; (e) $W_{\text {thr }}=0.32 \AA$ all redshifts, $0.03<z<1.67$, and $z<1$, total sample including blazars; (f) $W_{t h r}=0.32 A z<1$ and $z>1$, (solid points) $\left(\Omega_{M}, \Omega_{\mathrm{A}}\right)=(1.0,0.0)$, (dotted points) $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(0.3,0.7)$, metal line dz neglected in both cases


Figure 4.12. (a) Values of $\log \left[J\left(\nu_{0}\right)\right]$ recovered from simulated QSO spectra with proximity effect included: (dotted lines)- input $J\left(\nu_{0}, z\right)$, see Figure 4.11(a) (solid points)- recovered $J\left(\nu_{0}\right)$ for $W_{t h r}=0.32 \mathrm{~A}$ at all redshifts and at $z<1$ and $z>1$ separately; (b) same as (a), but $J\left(\nu_{0}\right)$ recovered using variable threshold


Figure 4.13. HI ionization rate versus redshift: (points)-constant equivalent width threshold maximum likelihood solutions from this paper, at $z<1$ and $z>1$, and from Paper II for $1.7<z<3.8$; (dashed line)- constant threshold solution to Equ. 4.13 for HST/FOS data alone; (solid line)- constant threshold solution to Equ. 4.14 with $\beta=1.46$ and $\beta=1.7$ for HST/FOS data and ground-based data from Papers I and II, (dotted line)- HM96 solution to Equ. 4.14


Figure 4.14. Histogram of results of jackknife measurements of HI ionization rate, $\Gamma$, for all lines at $z>1$ above variable equivalent width threshold; labels on highest $\Gamma$ bins indicate objects removed, see § 4.5.3


Figure 4.15. (a) Histogram of radio loudness (RL) values for QSOs in proximity effect sample, where $R L=\log [S(5 \mathrm{GHz})] / \log [S(1450 A)]$, includes blazars and objects with damped Ly- $\alpha$ absorption; (b) redshift versus RL for QSOs in proximity effect sample


Figure 4.16. $\log \left[J\left(\nu_{0}\right)\right]$ versus redshift: (lower limit at $z \sim 0$ )- Tumlinson et al. (1999); (upper limit at $z \sim 0$ )- Weymann et al. (2001); (filled triangle)- Shull et al. (1999); (upper limit at $z=0$ )- Weymann et al. (2001); (filled squares, bold error bars)- our results for $z<1$ and $z>1$; (other filled squares)- results from KF93, Paper II, Lu et al. (1996), Savaglio et al. (1997), and Williger et al. (1994); (upper limit at $z \sim 3$ )- Bunker et al. (1998); (solid curves)- HM96 models for two values of the global source spectral index, $\alpha_{s}$


Figure 4.17. $d \mathcal{N} / d z$ versus $z$ : solid and dashed lines show the relation for nonevolving Ly- $\alpha$ absorbers given by Equ. 4.18 for $\left(\Omega_{M}, \Omega_{\mathrm{A}}\right)=(1.0,0.0)$ and ( $0.3,0.7$ ), respectively; dotted lines are fits to low redshift data from Weymann et al. (1998) and to high redshift data of Kim et al. (1997); dashed-dotted lines are fits to low redshift data from Paper IV and to high redshift data from Paper I


Figure 4.18. (a) $d \mathcal{N} / d z$ versus $z$ : (solid points, dotted lines) $W_{\text {thr }}=0.24 \AA$ with fit to Equ. 4.19, (open points, dashed lines) $W_{t h r}=0.32 \AA$ with fit to Equ. 4.19, (thick solid line) Equ. 4.19 evaluated with HM96 parameters for $\Gamma(z)$ expressed by Equ. 4.14, (thin solid lines) Equ. 4.19 evaluated with parameters for $\Gamma(z)$ found in this paper; (b) $\Gamma(z)$ versus redshift expressed by Equ. 4.14 using HM96 parameters (thick solid line), using parameters found in this paper (thin solid lines), and using parameters found from fits to $d \mathcal{N} / d z$ for $W_{t h r}=0.24 \AA$ and $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$ (dotted iine) and $W_{t h r}=0.32 \AA$ and $\left(\Omega_{M}, \Omega_{\Lambda}\right)=(1.0,0.0)$ (dashed line),

## Chapter 5

## Lognormal Models of the Proximity Effect in Quasar Spectra

### 5.1 The Lyman $\alpha$ Forest

### 5.1.1 The Density and Velocity Fields

We construct density and velocity fields in the linear and mildly nonlinear regime using the lognormal (LN) approximation following the method outlined by BD97 for both standard CDM and $\Lambda$ CDM cosmologies for comparison with other simulation techniques.

In general, the LN technique consists of creating Gaussian random fields (GRFs) for the density and peculiar velocity using a one-dimensional matter power spectrum. The baryonic power spectrum is constructed by smoothing the dark matter power spectrum, $P(k)$, on the Jeans scale, $x_{b}=\lambda_{\mathrm{J}} /(2 \pi)$ :

$$
\begin{equation*}
P_{\mathrm{IGM}}(k)=\frac{P(k)}{\left[1+\left(x_{b} k\right)^{2}\right]^{2}}, \tag{5.1}
\end{equation*}
$$

where, at redshift $z$,

$$
\begin{equation*}
x_{b} \equiv \frac{1}{H_{0}}\left[\frac{2 \gamma k<T>}{3 \mu m_{p} \Omega_{0}(1+z)}\right]^{1 / 2} \tag{5.2}
\end{equation*}
$$

For the mean temperature of the IGM, $\langle T\rangle$, we use the density-averaged mean temperature. The terms $k$ and $m_{p}$ are the Boltzmann constant and proton mass; $\gamma$ is the ratio of specific heats, $\mu$ is the mean molecular weight of the IGM; and $H_{0}$ and $\Omega_{0}$ are the Hubble constant and total matter density parameter.

In general, the correlated, one-dimensional density and velocity fields are generated from linear combinations of two independent GRFs. These fields are evolved to the redshift of interest using the linear growth factors and are transformed to real
space via a Fast Fourier Transform. For further details on these calculations, see BD97. The LN transformation is applied to the overdensities:

$$
\begin{equation*}
\delta_{\mathrm{LN}}=\exp \left[\delta-\frac{<\delta^{2}>}{2}\right] \tag{5.3}
\end{equation*}
$$

Where $\delta$ is the linear density contrast with respect to the mean density, $\frac{\rho}{\rho_{0}}-1$. In each simulation, the spatial resolution in the GRFs is less than $5 \%$ of $x_{b}$ at the redshift of interest, typically $\sim 3-4 \mathrm{~h}^{-1} \mathrm{kpc}$. The box size of a given simulation is set by the line of sight length necessary to generate the spectral range of the QSO spectrum, generally $\sim 100-500 \mathrm{~h}^{-1} \mathrm{Mpc}$.

### 5.1.2 Comparison with $\mathbf{N}$-body simulations

The lognormal approximation was first introduced to treat the nonlinear evolution of dark matter (Coles \& Jones 1991). Here, we compare dark matter density in the linear regime and under the lognormal transformation with the results of an N -body calculation, kindly provided by V. Eke. The N-body simulation follows the evolution of $128^{3} 2.11 \times 10^{9} \mathrm{M}_{\odot}$ particles in 50 Mpc comoving box in a $\Lambda$ CDM cosmology with $\Omega_{0}=0.3$, vacuum energy density parameter $\Omega_{\Lambda}=0.7$, Hubble parameter $\mathrm{h}=H_{0} /(100$ $\left.\mathrm{km} \mathrm{s}^{-1} \mathrm{Mpc}^{-1}\right)=0.65$, and a power spectrum normalization defined by rms mass fluctuations on $8 \mathrm{~h}^{-1} \mathrm{Mpc}$ scales, $\sigma_{8}=0.9$. The linear dark matter density fields, Gaussian random fields generated using a dark matter power spectrum (Bardeen et al. 1986), are shown in the first column of Figure 5.1. We create the lognormal dark matter density fields by applying the lognormal transformation described in Equation 5.3 to the GRFs. Figure 5.1 illustrates the comparison between the dark matter density distributions for 100-200 lines of sight through a ACDM N-body simulation at $z=100$, 30,9 , and 2.33, and 100 realizations of a LN simulation for the same cosmological model at the same redshifts.

In both the linear and lognormal cases, the agreement is good at $z=100$ and steadily worsens as time progresses. At $z=9$, the peak of the distribution of linear
densities is already significantly shifted from that of the N -body simulation. The LN transformation leads to better alignment with the N-body distribution, but with a lower peak height.

By $z=2.33$, both distributions look rather different from the N -body distribution. The large variance of the DM Gaussian random field at low redshift has caused the LN transformation to shifted the mean of the distribution to a value less than one (see Figure 1 of Coles \& Jones, 1991). The LN distribution compares better with the N -body distribution than the linear density distribution in the sense that it skews the distribution towards lower densities rather than higher densities. At the highest densities, the LN distribution is well-matched to the N -body distribution.

In addition to the shift of the mean of the LN distribution relative to the N body distribution, the LN transformation tends to produce too few points at the mean density and too many in the wings of the distribution, particularly in the low density wing, relative to the N -body simulations. This shall have consequences on the distribution of baryon densities and the flux distributions in the spectra created from these simulations. We discuss this further below.

### 5.1.3 Physical Conditions in the Absorbing Gas

We depart from the treatment of BD97 in three ways in modeling the physical conditions in the intergalactic gas: (1) because the Ly- $\alpha$ forest data to which we will be comparing the models covers a range in redshift from $z=1.7$ to $z=4.1$, we use an IGM equation of state which incorporates its reionization history (Hui \& Gnedin 1997, HG97 hereafter), a redshift-varying polytrope, rather than the single polytrope approximation used by BD97; (2) we include helium in our overall ionization balance; and (3) we use the ionization rates of $\mathrm{H}^{0}, \mathrm{He}^{0}$, and $\mathrm{He}^{+}$as functions of redshift calculated by Haardt \& Madau (1996, HM96 hereafter) rather than from a power law form for the redshift dependence of the mean intensity background, $J\left(\nu_{0}\right)$.

The HM96 ionization rates reflect the integrated emission from the quasar population, with no contribution from stars. The exclusion of a contribution from star formation should not be of major consequence, as only 3 objects in our sample lie at $z>3.5$. Galaxies may contribute to the ionizing background at $z \sim 3$, but how significantly is a matter of debate (Steidel, Pettini \& Adelberger 2001, Giallongo et al. 2002). In terms of the number of ionizing photons need to bring agreement with the overall transmission of the IGM, it is not necessary to invoke a contribution from galaxies that dominates over that from quasars unless $z \geq 3.5$ (Haardt, Madau, \& Rees 1999).

Gas temperatures are calculated from the density-temperature relation derived by HG97:

$$
\begin{equation*}
T=T_{0}(z)(1+\delta)^{\gamma(z)-1}, \tag{5.4}
\end{equation*}
$$

where the temperature at mean density, $T_{0}$, and the polytropic index, $\gamma$, depend upon the redshift, the cosmological model, and the redshift of hydrogen reionization. We adopt $z=6.2$ as the redshift of hydrogen reionization, in agreement with recent observations of low transmitted flux in the spectra of quasars at $z=5.80-6.28$ (Becker et al. 2001, Djorgovski et al. 2001, Fan et al. 2002) as well as model predictions that the epoch of reionization can be constrained to a small window around this redshift (Gnedin 2002). If we instead adopt $z=10$ as the redshift of reionization, $\gamma(z)$ is increased and the density weighted mean temperature in the LN model is decreased by a few percent by $z=2$. The equation of state is not highly sensitive to the redshift of reionization because IGM should not retain a strong imprint of its reionization history provided it occurred at an early period (Miralda-Escudé \& Rees 1994, HG97). The lower temperatures would lead to a larger flux decrement in the LN spectra, which may require a different ionization rate scaling to match the data, but not one significantly different than the value discussed in Section 5.1.5.

The HG97 prescription for the IGM density-temperature relation does not include
the thermal effects of HeII reionization, which may occur at $z \sim 3$ (eg. Songaila \& Cowie 1996, Reimers et al. 1997, Songaila 1998, Kriss et al. 2001, see also MiraldaEscudé, Haehnelt, \& Rees 2000). This energy input would alter the slope of the equation of state and increase the temperature at mean density by a factor of $\approx 2$ (Schaye et al. 1999). We expect that this would have some effect on the HI optical depths calculated in our models, but that this effect would not be large enough to dramatically effect the results of our investigation of the proximity effect.

Equation 5.4 is a good representation of the IGM density-temperature relation for $\delta \lesssim 5$ (HG97). At higher densities, density-temperature relationship of intergalactic gas in photoionization equilibrium turns over due to recombination cooling (cf. Figure 1 of Haehnelt, Rauch, \& Steinmetz 1996). At high densities, therefore, a power law density-temperature relation yields temperatures larger than the balance between photoheating and line cooling requires. We impose this thermal photoionization equilibrium at high densities by calculating the equilibrium temperature of the IGM for $\frac{\rho}{\rho_{0}}=1-1000$. The HG97 density-temperature relation is scaled and connected smoothly to this equilibrium condition for each redshift, ensuring that the density-temperature relation in the simulation turns over at high densities (cf. Figure 1 of Haehnelt, Rauch, \& Steinmetz 1996).

Once a density and temperature are established at each point in the simulation, ionization balance is calculated using the HM96 ionization rates, assuming photoionization equilibrium, and the rate coefficients for collisional ionization of $\mathrm{H}^{0}, \mathrm{He}^{0}$, and $\mathrm{He}^{+}$and recombination of $\mathrm{H}^{+}, \mathrm{He}^{+}$, and $\mathrm{He}^{2+}$ as functions of temperature from Cen (1992) and Theuns et al. (1998a).

From the neutral hydrogen densities and the peculiar velocity field, the optical depth at each point in the spectrum is calculated assuming Voigt profiles:

$$
\begin{equation*}
\tau=N_{\mathrm{HI}} \sigma_{0} K(x, y) \tag{5.5}
\end{equation*}
$$

where $K(x, y)$ is the Voigt function. In this expression, $x$ is a dimensionless frequency:

$$
\begin{equation*}
x=\frac{c\left(\nu-\nu_{0}\right)}{\nu_{0}}\left(\frac{2 k T}{m}\right)^{-1 / 2} \tag{5.6}
\end{equation*}
$$

where $m$ is the mass of the absorbing atom, and $y$ is $\sqrt{\ln 2}$ times the ratio of damping to Doppler widths:

$$
\begin{equation*}
y=\frac{\nu_{0}}{c}\left(\frac{2 k T}{m}\right)^{-1 / 2} \frac{A_{21}}{4 \pi} \tag{5.7}
\end{equation*}
$$

where $A_{21}$ is the Einstein coefficient for the Ly- $\alpha$ transition.

### 5.1.4 Comparison with hydrodynamical simulations

SCDM SPH and $\Lambda C D M$ Eulerian Models- Mean Decrements: We compare the mean and distribution of flux decrements in the spectra generated with our lognormal model with those listed in Rauch et al. (1997, R97 hereafter) for high resolution quasar spectra from the HIRES instrument on the Keck telescope as well as for the hydrodynamical simulations they use to match the Keck data, a standard CDM (SCDM) smoothed particle hydrodynamics (SPH) simulation (Croft et al. 1997) and a $\Lambda$ CDM Eulerian simulation (Cen et al. 1994, Miralda-Escudé et al. 1996). We restrict the comparison to their $z=2$ simulations, as we can use the same density-temperature relations in their simulations at this redshift by consulting their Figure 7. In particular, we attempt to mimic the reionization heating processes treated in the Eulerian simulations by using the density-temperature relation given in this figure. With the LN model, we simulate the Keck data presented by R97 for the combinations of the baryon density, $\Omega_{b}$, and the HI photoionization rate listed in their Table 4. As described by R97, we weight each pixel's contribution to the mean decrement by the signal-to-noise ( $\mathrm{S} / \mathrm{N}$ ) and scale the optical depths in each spectrum to the central redshift of the calculation. Our standard CDM (SCDM) LN models fare better in matching the simulations and the Keck data than the $\Lambda$ CDM models. The mean flux decrements for the SCDM and $\Lambda$ CDM model spectra are 0.155 and 0.174 , respectively. R97 find 0.154 and 0.152 .

We do not have the simulation data in hand to directly compare the LN cumulative flux decrement distributions (FDDFs) with the hydrodynamical simulation FDDFs, but their Figures 3 and 4 indicate that they match the Keck data quite well. We therefore compare the LN simulations described here directly to the $z=1.5-2.5$ FDDF of the Keck data, provided to us by M. Rauch. The Kolmogorov-Smirnov probabilities, $Q(\mathrm{KS})$, associated with these two pairs of simulation cumulative distributions are 0.35 and 0.002 . We find better agreement between the $\Lambda$ CDM LN model spectra and the Keck data by using a higher photoionization rate than that found by R97. Specifically, we require $\Gamma_{\mathrm{HI}}=1.37 \times 10^{-12} \mathrm{~s}^{-1}$ at $z=2$, giving a KS probability of 0.72 , but a lower mean decrement than R97, 0.134 . This combination of $\Gamma_{\mathrm{HI}}$ and $\Omega_{b}$ results in $\mu=\left(\frac{\Omega_{b} h^{2}}{0.0125}\right)\left(\frac{100 \mathrm{~km} \mathrm{~s}^{-1} \mathrm{Mpc}^{-1}}{H(z)}\right) \Gamma_{-12}^{-1}=1.22$, compared to the value of 1.88 quoted by R97 for the $\Lambda$ CDM simulations. The mean flux decrements are listed in Table 5.1 and the cumulative distributions of flux decrements are shown in Figure 5.2.
^CDM SPH Model- Direct Lines of Sight: We compare our lognormal simulations to spectra generated from lines of sight through a hydrodynamical simulation in a $\Lambda$ CDM cosmology, namely the SPH simulations presented by Davé et al. 1999. For the parameters used, see Table 1 of that paper.

We generate 400 independent lognormal spectra using the same box size, cosmological model parameters, and ionization and recombination rates as the SPH simulations. We calculate gas temperatures from a polytropic approximation to the density-temperature relation of the SPH data cube, $\log (T)=0.60 \log [\mathrm{n}(\mathrm{H})]+7.21$. The absence of scatter in the LN density-temperature relation has little effect on the mean flux decrement in the simulated spectra. We construct FDDFs from these spectra and compare these with the FDDFs derived from 400 lines of sight through the SPH simulations. These are shown in Figure 5.3. The average flux decrement we find from 400 realizations of the LN model at $z=2$ is 0.206 . The same number of lines of sight through the SPH simulation cube gives $\langle\mathrm{D}\rangle=0.193$. A hotter density-
temperature relation is required by the LN simulations to give good agreement with the SPH spectra. Using relation from the $\Lambda$ CDM Eulerian simulation discussed above (cf. Figure 7 of R97) for these LN simulations, we find $<\mathrm{D}\rangle=0.190$, in much better agreement with the decrement in the SPH spectra. However, the value of $Q(K S)$ from the K-S comparison of this LN flux decrement distribution and the SPH FDDF is negligible, indicating that while the mean decrements may match each other well, the flux distributions have significantly different shapes.

In order to determine the source of the discrepancy between these models, we plot the distribution of neutral fractions, optical depths, and hydrogen densities at $z=2$ in Figure 5.4. In Figure 5.4(a), we use the SPH densities and our ionization subroutine to calculate neutral fractions at each point in the SPH simulation cube. These compare well with the neutral fractions found by the SPH code. In Figure 5.4(b), we use the densities and neutral fractions from the SPH code to calculate optical depths from our code. These compare well with the optical depths from the SPH code itself. The discrepancy between the SPH and LN codes arises in the density distributions themselves, as illustrated in Figure 5.4(c). Here, we plot the total hydrogen densities, in units of the mean density, for both simulations. It is not surprising that the LN model underproduces the number of points in the high density wing of the distribution, given that this method does not treat highly nonlinear evolution in the IGM. But it is clear that the lognormal approximation underproduces the number of points at the mean density, placing these points instead at low densities. This overabundance of low density- and, with the polytropic density-temperature relation, low temperature- points is contributing to the disagreement between the FDDFs at low flux decrements, and the disagreement in the overall shape of the LN FDDF relative to that of the SPH FDDF. This difference in the density distributions is a reason to consider other semi-analytic methods for generating Ly- $\alpha$ forest spectra, such as methods based on the Zel'dovich approximation (Hui, Gnedin, \& Zhang 1997, Viel et al. 2002) or a method by which gas densities are estimated directly from the evolved
dark matter density and peculiar velocity fields generated by N -body simulations (Viel et al. 2002). We emphasize that we use the LN method because it provides a means of constructing quasar spectra quickly so that we may perform several realizations of the data set and explore different scenarios for quasar placement within the LN density fields. As we are mainly interested in the properties of the IGM near quasars and the relative difference in absorption in the IGM far from and near quasars due to the proximity effect, we will leave treatment of other models for future work and will proceed with the LN method as a first approximation.

### 5.1.5 The Background Ly- $\alpha$ Forest Model

To choose an underlying model for the Ly- $\alpha$ forest upon which to imprint the proximity effect signature we compare our LN models to the MMT QSO absorption line data presented in Scott et al. (2000a) and used to measure the ionizing background at $z \approx 2$ in Scott et al. (2000b). We investigate a $\Lambda$ CDM "concordance" cosmological model: ( $\Omega_{0}=0.3, \Omega_{\Lambda}=0.7, \mathrm{~h}=0.65$ ). We use $\sigma_{8}=0.9$, in agreement with the local cluster abundance (Eke, Cole, \& Frenk 1996) and the 4 -year COBE results (Bunn \& White 1997). We adopt $\Omega_{b} \mathrm{~h}^{2}=0.019$ from measurements of $\mathrm{D} / \mathrm{H}$ in Ly- $\alpha$ absorbers (Burles \& Tytler 1998a,b, Kirkman et al. 2000). We use the Sugiyama (1995) fit for the shape parameter for this model, 0.157 .

We perform ten LN realizations of the full sample of 78 quasars. These data comprise the samples of moderate resolution quasar spectra from the Palomar 5-meter Telescope and the Multiple Mirror Telescope presented in Bechtold 1994, Dobrzycki \& Bechtold 1996, and Scott et al. 2000a and summarized in Scott et al. 2000a. The gravitational lens Q1422+231 is excluded from the simulated samples due to the lack of information about its intrinsic Lyman limit luminosity. The majority of the data come from the MMT, so we will refer to this as the MMT sample.

Flux Statistics- Comparison with MMT and Keck Data: We simulate the MMT data from Scott et al. (2000a) at the resolution (median $=75 \mathrm{~km} \mathrm{~s}^{-1}$ ) and continuum $\mathrm{S} / \mathrm{N}$ (median $\sim 10$ ) of the data itself, and at a resolution of $6.6 \mathrm{~km} \mathrm{~s}^{-1}$ and median continuum S/N of $\sim$ 20, approximating that of Keck/HIRES data. We compare the Keck resolution simulations with the FDDF for Keck data in R97, and the MMT resolution simulations with the MMT data itself. These FDDFs are shown in Figure 5.5. There is good agreement between the LN simulations and both the MMT and the Keck data for the same scaling of the HM96 photoionization rates as a function of redshift. We will refer to this scaling factor throughout the paper as $f_{\Gamma}$. This result gives us confidence that the continuum fits to the MMT spectra are reliable, because any systematic depression of the continuum fit caused by blending in the moderate resolution MMT data, with respect to the level in the higher resolution Keck spectra, would lead to the requirement of a larger value of $f_{\Gamma}$ to match the MMT data to the LN simulations than is needed to match the Keck data.

We find the best value of $f_{\Gamma}$ by performing one realization of the quasar sample at both Keck and MMT resolution for various values of $f_{\Gamma}$. The agreement between the LN simulations and the data is quantified in terms of the mean decrement, $<\mathrm{D}\rangle$, over some redshift range, and the KS probability that the cumulative distributions of flux decrements in the simulations and the data are the same, $Q(\mathrm{KS})$. Specifically, the best values are in the range $f_{\Gamma}=1.53,1.43,1.33$, or $f_{\Gamma}^{-1}=0.65,0.70,0.75$, and the value we choose as the best scaling factor is $f_{\mathrm{r}}=1.43$.

The $\mathrm{LN} /$ Keck simulations give $\langle\mathrm{D}\rangle=0.135$ at $\langle z\rangle=2.29$, where R97 quote 0.148 for the Keck data, and $Q(\mathrm{KS})=0.92$ for these two distributions. The LN/MMT simulations give $\langle\mathrm{D}\rangle=0.128$ at $\langle z\rangle=2.07$. The MMT data give $\langle\mathrm{D}\rangle=0.129$, and $Q(\mathrm{KS})=0.72$ for these two distributions. For comparison, at these same mean redshifts, the $\mathrm{LN} /$ Keck simulations give $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.130,0.94]$ for $f_{\Gamma}=1.53$ and $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.143,0.77]$ for $f_{\Gamma}=1.33$ while the $\mathrm{LN} / \mathrm{MMT}$ simulations show $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.099,0.13]$ for $f_{\Gamma}=1.53$ and $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.133,0.47]$
for $f_{\Gamma}=1.33$.
This scaling of the HM96 ionization rates for the LN models matches less well to the mean decrement of the data at $z=2.5-3.5$. The LN/Keck simulations give $<\mathrm{D}\rangle=0.299$ at $\langle z\rangle=3.02$, where R97 quote 0.316 for the Keck data, with $Q(\mathrm{KS})=0.31$. The LN/MMT models $\langle\mathrm{D}\rangle=0.307$ while the data show $<\mathrm{D}\rangle=$ 0.250 at $\langle z\rangle=2.85$, with a low KS probability, $Q(\mathrm{KS})=0.007$. Therefore, the LN simulations have some difficulty reproducing the observed flux decrements equally well at $z=1.5-2.5$ and at $z=2.5-3.5$ for the same $f_{\Gamma}$. Again, for comparison, the $\mathrm{LN} /$ Keck simulations give $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.289,0.19]$ for $f_{\Gamma}=1.53$ and $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.324,0.41]$ for $f_{\Gamma}=1.33$ and the LN/MMT simulations show $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.254,0.63]$ for $f_{\Gamma}=1.53$ and $[<\mathrm{D}>, Q(\mathrm{KS})]=[0.318,0.001]$ for $f_{\Gamma}=1.33$.

The $Q(\mathrm{KS})$ indicates that the match to the Keck data at $z=2.5-3.5$ is reasonable for $f_{\Gamma}=1.43$. Also, there are approximately $50 \%$ more pixels in the MMT data at $z=1.5-2.5$ than at $z=2.5-3.5$. For these reasons, we adopt $f_{\Gamma}=1.43$ as the best scaling factor for the HM96 ionization rates, as this gives the best agreement between the LN simulations and the MMT data for the lower redshift range, and reasonable agreement with the Keck data at $z=1.5-2.5$ and $z=2.5-3.5$.

In Figure 5.6, we show a histogram of the values of $\langle\mathrm{D}\rangle$ derived from each of the ten realizations of LN simulations of the MMT data set. These values are also tabulated in Table 5.1. In the left panel, we show the values from a set of simulations in which the quasars are placed at random positions in the density field. The values in the right panel of this figure are from a set of "high density" simulations in which quasars are placed in $3 \sigma$ overdensities in the LN density fields which have been smoothed on $1 \mathrm{~h}^{-1} \mathrm{Mpc}$ scales to model the clustering of matter around quasars and explore the consequences for the proximity effect. We discuss these models further in § 5.2.2. Because we exclude proximity effect regions in the calculations of $<\mathrm{D}>$ from the simulated spectra, these values should not be substantially different from
each other, and these histograms illustrate that they are not.
The differential flux distribution function, $P(F)$, for the simulations in which quasars are placed at random positions is plotted in the top panel of Figure 5.7. For the full redshift range of the data, we calculate a $\chi_{\nu}^{2}$ of $8.8\left(Q\left(\chi^{2}\right)=7.0 \times 10^{-16}\right)$ from a full covariance matrix based on 500 bootstrap samples of the MMT data (McDonald et al. 2002). Formally, this agreement is not good. But, as stated above, since we are not attempting to model the detailed flux distribution in the $\mathrm{Ly}-\alpha$ forest, we will accept the global agreement in the mean decrements and cumulative flux decrement distributions as sufficient for our purpose of examining the proximity effect. In the lower panel of this figure, we show the flux distribution for the simulations in which quasars are placed in $3 \sigma$ overdensities, which we discuss further below.

Line Statistics- Comparison with MMT Data: Examples of simulated spectra are shown in bottom panels of Figure 5.8. Comparing with the real spectra, shown in the top panels of the figure, it is evident that the simulations compare well visually with the data.

We identify significant absorption features and measure line equivalent widths in the simulations in the same way as was done on the data (see Scott et al. 2000a). As in the analysis of Scott et al. (2000a), we consider only lines of $5 \sigma$ significance or greater, where the significance is defined by the ratio of measured line equivalent width to the $1 \sigma$ error in the equivalent width calculated from the smoothed detection threshold as described by Bechtold et al. (2002). From Monte Carlo simulations, Scott et al. (2000a) found that blending in the moderate resolution MMT data limits the completeness of the $5 \sigma$ line lists to $55 \%$. Following the analysis of Scott et al. (2000a), we use either a constant rest equivalent width threshold of 0.16 A. . 0.32 $\AA$, or we allow this threshold to vary with $\mathrm{S} / \mathrm{N}$, and we employ the same maximum likelihood method described in that paper and in Dobrzycki et al. (2002) to calculate
the line number density evolution parameters $\mathcal{A}_{0}$ and $\gamma$ :

$$
\begin{equation*}
\frac{d \mathcal{N}}{d z}=\mathcal{A}_{0}(1+z)^{\gamma} \tag{5.8}
\end{equation*}
$$

These values for each realization and for $0.16 \AA, 0.32 \AA$, and variable equivalent width thresholds, are tabulated in Table 5.2, and in Figure 5.9, we compare the statistic $\gamma$ derived from the data and presented in Scott et al. (2000a) to that derived from the simulation. In the left panel, we present one of the ten realizations of the LN simulations and in the right panel, we compare the mean and variance of the values from all ten realizations with the $\gamma$ found from the MMT data itself. The values of $\gamma$ derived from the simulations agree with those calculated from the MMT data to within the statistical uncertainties, though the simulations do systematically produce slightly larger values of $\gamma$ than found from the data. This can also be seen in the histograms of all the values of $\gamma$ from all ten of the LN realizations of the MMT data set, shown in Figure 5.10. We show the results of both the random and high density simulations, though the values of $\gamma$ from these two simulations should not differ dramatically from one another in principle because proximity effect regions are excluded from the calculations of $\gamma$.

### 5.2 The Proximity Effect

We model the proximity effect in the generated spectra by placing a quasar with a specific Lyman limit flux density at a specific redshift and modeling the effect of that quasar's radiation field on the surrounding IGM. The Lyman limit fluxes and redshifts of the quasars match those of the objects in the MMT data sample. See Tables 3 and 5 of Scott et al. (2000b).

### 5.2.1 QSO Radiation Field

The Lyman limit intensity at the redshift of an absorber, $z_{a}$ from a quasar at redshift $z_{q}$ with observed Lyman limit flux $f\left(\nu_{0}\right)$ is computed from

$$
\begin{equation*}
F^{q}\left(\nu_{0}\right)=\frac{f\left(\nu_{0}\right)}{\left(1+z_{q}\right)} \frac{d_{L}^{2}\left(z_{q}\right)}{r_{L}^{2}\left(z_{a}, z_{q}\right)} \tag{5.9}
\end{equation*}
$$

where $d_{L}\left(z_{q}\right)$ and $r_{L}\left(z_{a}, z_{q}\right)$ are the observer-quasar and absorber-quasar luminosity distances, respectively.

The relevant parameter for characterizing the proximity effect is $\omega$, the ratio of quasar to background ionization rates (BDO). If one assumes that the spectral shape of each sample quasar is identical to that of the background, this ratio becomes $F^{q}\left(\nu_{0}\right) / 4 \pi J\left(\nu_{0}\right)$. However, this is likely not a valid assumption, given the intrinsic variation in quasar spectral energy distributions and given that IGM reprocessing of quasar radiation will result in a background spectrum that is softer than the emitted quasar spectrum (HM96, Fardal, Giroux, \& Shull 1998). We avoid this assumption by using each sample quasar's UV spectral index (cf. Table 3 of Scott et al. 2000b) to calculate $\omega$ as the ratio of ionization rates, $\Gamma_{q} / \Gamma_{b g}$, where $\Gamma_{b g}$ is the HM96 ionization rate, scaled by the factor, $f_{\Gamma}$, necessary to bring agreement with the observed mean transmission of the IGM at the relevant redshifts. As discussed in Section 5.1.5, we found $f_{\Gamma}=1.43$.

At every point in the LN density fields, the ionizing radiation is then the sum of the metagalactic background field and the local quasar field. To include the proximity effect in the model spectra, then, the ionization state of the gas is calculated using this summed field assuming the gas is in photoionization equilibrium, and the optical depth is calculated from the resulting neutral fraction. To address the question of whether the simple quasar photoionization model for the proximity effect is valid, we compare our models which include the ionization effects of quasars to the QSO absorption line data of Scott et al. (2000a). In the next sections, we examine whether these models reproduce the proximity effect signature seen in the observed quasar
spectra. First, we discuss the two different scenarios under which quasars have been placed in the model density fields.

### 5.2.2 Clustering Near Quasars

In a hierarchical scenario of structure formation, quasars are expected to occupy regions of the highest overdensities (Haehnelt \& Rees 1993). The peculiar velocities of matter clustered in the potential wells of galaxies and small groups of galaxies can influence the proximity effect signature by redshifting absorption features into the proximity effect region or to wavelengths greater than the Ly- $\alpha$ emission line (Loeb \& Eisenstein 1995). Pascarelle et al. (2001) argue that clustering of galaxies around quasars may lead proximity effect measurements to overestimate $J\left(\nu_{0}\right)$ at $z<1$ by a up to a factor of 20 . Also, the fact that absorption arising from high density regions will not lie on the linear part of the curve-of-growth may also be expected to influence the proximity effect signature as the line equivalent widths will not respond in a linear fashion to changes in HI column density (Scott et al. 2000b, 2001).

We address the issue of clustering by running a set of simulations using the best model parameters described above, but placing quasars preferentially in high overdensity regions of the density fields. In this prescription, we boxcar smooth the density field on a length of 1 comoving Mpc, and identify a region in the smoothed field with a $3 \sigma$ overdensity. We model a scenario in which quasars inhabit environments similar to large groups or clusters of galaxies by placing them at the centers of these overdense regions. These regions are also regions where the peculiar velocity gradients are highest, so we treat both effects noted above. However, this model does not account for hot ( $\sim 10^{7}-10^{8} \mathrm{~K}$ ) X-ray emitting gas detected in groups and clusters of galaxies (eg. Forman \& Jones 1982, Mulchaey 2000), including those which host quasars (Hall, Ellingson, \& Green 1997). This shock-heated gas is highly ionized, and accounting for it in the model would reduce the enhancement of absorption near the quasars caused
by placing them in these overdense regions. In previous sections, we have referred to this set of simulated spectra, in which quasars inhabit high density regions in the density distributions, as the "high density" simulations, while the simulations in which quasars occupy random positions within the density fields at any given redshift are the "random" simulations, and we will continue this nomenclature throughout the rest of this paper. We have used the same background Ly- $\alpha$ forest model as was used in the random simulations, as these models were calibrated to the data by the flux decrements in the Ly- $\alpha$ forest, excluding regions affected by the proximity effect. As described in Section 5.2.3, the division between the Ly- $\alpha$ forest and the proximity effect region in each spectrum is chosen to be $\omega=0.1$. In the lower panel of Figure 5.7, we plot the differential flux distribution of these simulations, compared with that of the MMT data. Though visual inspection of Figure 5.7 indicates that these simulations give better agreement in the highest and third highest flux bins, they give $\chi_{\nu}^{2}=20$. with respect to the 500 bootstrap samples of the data discussed in $\S 5$ 5.1.5 above, versus $\chi_{\nu}^{2}=8.8$ for the random simulations. For some of the ten LN realizations of the full data MMT set, however, the high density simulations give a lower $\chi_{\nu}^{2}$ than the random simulations, so this test alone cannot discriminate between these two proximity effect models.

Figure 5.11 shows the bin-by-bin comparison of the flux in the random and high overdensity simulations for the full redshift range of the data, ie. with no exclusion of regions expected to be influenced by the proximity effect. The $\mathrm{F}=0.9$ flux bin does not change between these two simulations, and the largest discrepancy between the two models is in the $\mathrm{F}=1.0$ bin, where the high density simulations show a higher relative fraction of pixels. This is not unexpected due to the fact that placing quasars in high overdensity regions within the simulation box will tend to ionize these rare high density regions relative to their ionization state in the random simulations, leading to more pixels at high flux levels and fewer pixels at lower flux levels, a trend also visible in Figure 5.11.

### 5.2.3 The Spectral Signature of the Proximity Effect

We now explore the ramifications on the simulated quasar spectra of the quasar fluxes that we have included in the ionization balance in our LN density fields. We do this by examining the mean optical depths and the absorption line distributions in regions of the simulated Ly- $\alpha$ forest spectra near the quasar emission lines.

Mean Optical Depth Near Quasars: Following Press, Rybicki, \& Schneider (1993, PRS hereafter) we fit the mean Ly- $\alpha$ optical depth, $\bar{\tau}_{\alpha}$, in $100 \AA$ bins in the spectra to the function

$$
\begin{equation*}
\bar{\tau}_{\alpha}(z)=A(1+z)^{1+\gamma} \tag{5.10}
\end{equation*}
$$

PRS find $A=0.0037$ and $\gamma=2.46$ for 29 low resolution spectra of quasars at $2.5<z<4.3$. The results of the fits to all ten realizations of the simulated data set in the random and high density scenarios are listed in Table 5.3. The errors are derived from the least square fits to Equation 5.10 by setting the RMS error on each point equal to the square root of the median variance of all the flux bins used in the fit. The fits are performed separately for the Ly- $\alpha$ forest regions of the spectra with a proximity effect cutoff of $\omega=0.1$, and for the entire redshift extent of the spectra, including the proximity effect regions. The fits with the proximity regions excluded and included are shown in Figure 5.12. Zuo \& Lu (1993) point out that $\gamma$ is expected to be smaller if the proximity effect regions are included, similar to the way it is flatter if these regions are included in the fit to the line distribution with redshift given by Equation 5.8. Restricting the fits to lie within approximately the same redshift range, we find this in the fits to the flux points of the MMT data, for which we derive $\gamma=1.41$ for the $\mathrm{Ly}-\alpha$ forest and $\gamma=0.24$ for the $\mathrm{Ly}-\alpha$ forest plus proximity regions. The points at $\omega>0.1$ are plotted as open squares in Figure 5.12 and are excluded from the Ly- $\alpha$ forest only fits, which are shown as thick dashed lines. These points are added to the fits which include the proximity effect regions, shown as dotted lines in Figure 5.12.

Many of these bins lie at $<\mathrm{F}>\sim 1$, flattening the mean optical depth distribution, and thus lowering $\gamma$ and raising the normalization, $A$. The simulations also show this effect, $\gamma=2.34$ in the forest alone and $\gamma=1.77$ when including the proximity regions. The effect is somewhat less dramatic for the high density simulations, for which the $\gamma$ 's become 2.40 and 1.96 for the exclusion and inclusion of spectral points at $\omega>0.1$, respectively. The values of $\gamma$ in both simulations are larger than those in the data, and the small statistical error bars indicate that these differences are significant. However, the amount by which $\gamma$ is depressed by the proximity effect in the simulations is consistent with the data, and the agreement between the values of $\gamma$ derived from the absorption lines in the simulation and those derived from the data gives us confidence that our $\mathrm{Ly}-\alpha$ forest models are reasonable.

Absorption Lines Near Quasars: Another prediction of the photoionization model of the proximity effect is that the line deficit near quasars with respect to the canonical power law given by Equation 5.8 should be more pronounced for high luminosity objects than for low luminosity objects. Dividing the MMT sample into high and low luminosity objects at $\log \left[\mathrm{L}\left(\nu_{0}\right)\right]=31.1$, and calculating the line deficit as a function of distance from the quasar in a $\Lambda$ CDM cosmology, we find no significant difference in the deficit of lines with $W>0.32 \AA$ within $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ of the quasars in the MMT data. In fact, we find a deficit of $2.9 \sigma$ significance for low luminosity quasars and $2.1 \sigma$ for high luminosity quasars ${ }^{1}$. This sample spans a factor of $\sim 300$ in quasar luminosity, but most objects posses a luminosity near the mean value, and the mean luminosities of the high and low luminosity subsamples are only a factor of $\sim 5.5$ different from one another. Because lines of $0.32 \AA$ equivalent width and greater lie on the flat part of the curve of growth where the relationship between HI column density and equivalent width is not linear, we also examine a smaller equivalent width limit of 0.16 A . Lines of equivalent width greater than $0.16 \AA$ also show no significant difference between

[^0]low and high luminosity quasars within $2 h^{-1} \mathrm{Mpc}, 4.7 \sigma$ and $4.2 \sigma$, respectively. In Figure 5.13, we show the line deficit in the real quasar sample and in one realization of the simulated MMT sample as a function of distance from the quasars for lines of equivalent widths greater than $0.16 \AA$ and $0.32 \AA$. In Figures 5.14 and 5.15 , we show histograms of the line deficits within $2 h^{-1} \mathrm{Mpc}$ in all the realizations of the LN models for these two equivalent width thresholds.

Figure 5.13 indicates that the random simulations reproduce the general pattern of line deficits more faithfully than the high density simulations. Figures 5.14 and 5.15 illustrate that both the random and high density simulations produce line deficits in good agreement with the data for the high luminosity subsample of quasars. Overall, however, these histograms also indicate that the random simulations tend to give a larger line deficits than the data and that the high density simulations have a tendency to show a smaller line deficits than the data.

In the realization of the random simulations shown in Figure 5.13, the deficit of $W>0.32 \AA$ lines within the first $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ is $3.1 \sigma$ for low luminosity objects and $2.1 \sigma$ for high luminosity objects. This is in quite good agreement with the line deficits seen the MMT data, demonstrating that a lack of a correlation of line deficit with quasar luminosity for strong lines does not indicate the absence of a proximity effect, or the invalidity of the photoionization model. In the next bin, extending out to 4 $\mathrm{h}^{-1} \mathrm{Mpc}$, the high luminosity objects do show a somewhat more pronounced deficit, $4.7 \sigma$, compared to $3.8 \sigma$ for the low luminosity quasars. The deficit of $W>0.16 \mathrm{~A}$ lines is more pronounced for high luminosity objects than for low luminosity objects within $6 \mathrm{~h}^{-1} \mathrm{Mpc}$, however: $6.5 \sigma, 5.5 \sigma$, and $2.9 \sigma$ versus $5.9 \sigma, 3.1 \sigma$, and $1.2 \sigma$. This is marginally larger than the deficit seen in the MMT data.

In this realization of the high density simulations, the line deficits in all cases, strong and weak lines in low and high luminosity quasar subsamples, are reduced substantially from those observed in the random simulations, as one might expect. With the exception of the deficit of $W>0.32 \AA$ lines in the spectra of the low
luminosity objects, $2-4 \sigma$ in the first four $2 h^{-1} \mathrm{Mpc}$ bins, the line deficits in the high density simulations are consistent with no proximity effect at all for the realization shown in Figure 5.13.

Figures 5.14 and 5.15 indicate that the deficits of strong and weak lines for high luminosity quasars are reproduced rather well in both the random and high density models. There is a slight tendency for the random simulations to produce more significant line deficits and for the high density simulations to produce less significant line deficits in the spectra of high luminosity quasars, but the only case in which this trend is statistically significant is the case of the deficit of $0.16 A$ lines in the high density simulations of the low luminosity subsample of quasars. A higher degree of certainty will require a larger number of realizations of the data set. In general, the simulated spectra of low luminosity quasars show do the trend mentioned above somewhat more clearly for both strong and weak lines, that is, the simulations in which quasars inhabit random positions in the density field tend to produce larger line deficits than are seen in the data while the opposite is true for simulations in which quasars inhabit regions in which the smoothed density is $3 \sigma$ larger than the mean density. One way to remedy this discrepancy in the high density simulations may be to correlate the overdensity in which quasars lie with their luminosity. If lower luminosity quasars reside in overdensities less than $3 \sigma$ above the mean, this should boost the line deficit seen for these objects, though not to the levels seen in the random simulations.

### 5.2.4 Measurement of the Ionizing Background

We apply the maximum likelihood method discussed in Scott et al. 2000b to measure the ionizing background from the sample of simulated quasar spectra in the same way as it was measured for the data in these papers. We perform the maximum likelihood analysis described in that paper on lines with $W>0.32 \AA$ to derive both the single
best-fit value of the HI ionization rate, $\Gamma$, over the redshift range $z=1.9-4.1$. Since we know the redshift dependence of the HI ionization rate input into the simulations, we also solve for $f_{\Gamma}$, the best-fit scaling of the HM96 parametrization of $\Gamma(z)$ :

$$
\begin{equation*}
\Gamma(z)=f_{\Gamma} A(1+z)^{B} \exp \left(\frac{-\left(z-z_{c}\right)^{2}}{S}\right) \tag{5.11}
\end{equation*}
$$

where $\left(A, B, z_{\mathrm{c}}, S\right)=\left(6.7 \times 10^{-13}, 0.43,2.3,1.95\right)$ matches the simulation input well in this redshift range.

The results of the maximum likelihood analysis on one realization of the simulations are shown in Figure 5.16. The dashed black line in the top and middle panels shows the value of the HI ionization rate used in the simulations. Recall that the photoionization rate input into the simulations was a scaling of Equation 5.11, chosen to match the flux decrements in the simulation Ly- $\alpha$ forest spectra with both MMT and Keck data, $f_{\Gamma}=1.43$. The maximum likelihood solutions for both $\Gamma$ and $f_{\Gamma}$ in this realization of the random simulations reproduce the input values well. Any clustering of material around quasars relative to the general IGM, where the function relative to which we look for a deficit of absorption is defined, should cause us to underestimate the extent of the proximity effect and hence overestimate the background. Indeed, the high density simulation realization reproduces the input $\Gamma$ at the median redshift of the sample, but overestimates $f_{\Gamma}$ by $1.2 \sigma$. In nine of the ten realizations of the MMT data set, the high density simulations return larger values of $\Gamma$ and $f_{\Gamma}$ than the corresponding random simulations.

Performing this analysis on the MMT data gives $\log (\Gamma)=-11.82_{-0.17}^{+0.20}$, and $f_{\Gamma}=$ $1.42_{-0.42}^{+0.78}$, in excellent agreement with this realization of the random simulations. This result is shown in the bottom panel of Figure 5.16. The redshift range of this solution is indicated by the horizontal bar. It does not extend to $z=4.1$ as the simulations do, because some of the quasars in the MMT sample, particularly Q0000263 ( $z_{\mathrm{em}}=4.1$ ), show associated absorption, ie. a metal system within $5000 \mathrm{~km} \mathrm{~s}-1$ of the quasar emission line, and were thus excluded from the proximity effect analysis.

The distributions of results, which are listed in Table 5.4, for the single-valued $\Gamma$ solutions and the HM96 scaling factors, $f_{\mathrm{r}}$, are shown in Figure 5.10. The arrows on these histograms mark the values input into the simulations, which were chosen to match the mean decrement in the Ly- $\alpha$ forest data, and the values derived from the maximum likelihood analysis on the MMT data. The values of $f_{\Gamma}$ derived from the random simulations agree quite well with the input values, while those derived from the high density simulations tend to be larger than the input, with a large spread. The values of $\Gamma$ derived from the random simulations tend to slightly underestimate the input and data values, while those derived from the high density simulations are more evenly distributed around the input and data values.

The mean ionization rate derived from the LN simulations in which quasars are placed in random positions in the density field is smaller than the input ionization rate, by a factor of 1.7 , or $1.3 \sigma$. However, the solution for $f_{\Gamma}$ measured from these simulated spectra is fully consistent with the input ionization rate. The mean ionization rate from all ten realizations of the simulations in which the quasars are placed in high density regions is consistent with the input ionization rate at the median redshift, larger by $0.4 \sigma$. The mean value of $f_{\Gamma}$ is 3 times the input value, $1 \sigma$ given the spread in the results.

### 5.2.5 Quasar Systemic Redshifts

Uncertainty in quasar systemic redshifts is a major source of systematic uncertainty in the ionization rate derived from the proximity effect analysis. Scott et al. (2000b) treated this problem by using quasar redshifts derived from [OIII] $\lambda 5007$ and Mg II emission lines whenever they were available and applying a global velocity shift to the redshifts measured from the Ly- $\alpha$ emission line. This shift was determined by comparing the redshifts derived from [OIII] 25007 and Ly- $\alpha$ in the same object for a sample of emission line data from that work, supplemented with data from $\mathrm{M}^{c}$ Intosh
et al. (1999).
To directly determine the magnitude of this effect, we treat our input simulation quasar redshifts as systemic and attempt to reproduce the uncertainty in real quasar systemic redshifts by applying a redshift transformation to each:

$$
\begin{equation*}
z=z_{q}-z_{\mathrm{sys}}+z_{\Delta v} \tag{5.12}
\end{equation*}
$$

where $z_{q}$ is the quasar emission redshift used in the simulation, the true quasar redshift. The term $z_{\text {sys }}$ is a redshift difference from a velocity shift which is drawn from a Gaissian distribution with mean $418 \mathrm{~km} \mathrm{~s}^{-1}$ and $\sigma=920 \mathrm{~km} \mathrm{~s}^{-1}$. This is the mean and standard deviation of the blueshifts of Ly- $\alpha$ emission with respect to [OIII] measured by Scott et al. (2000b). In that work, emission redshifts from [OIII] or some other reliable indicator of systemic redshifts were used when possible, but in for some quasars, only a $\mathrm{Ly}-\alpha$ redshift was available. The term $z_{\Delta v}$ is the global velocity correction of $400 \mathrm{~km} \mathrm{~s}^{-1}$ applied to all Ly- $\alpha$ redshifts by Scott et al. (2000b) in the attempt to convert these redshifts to true quasar systemic redshifts.

We choose one LN realization of the of the MMT data set and, within the maximum likelihood analysis, transform the each quasar redshift according to Equation 5.12 with no global correction, $z_{\Delta v}=0 \mathrm{~km} \mathrm{~s}^{-1}$, mimicking a proximity effect analysis done with no attempt to correct for quasar systemic redshifts. This is repeated nine additional times on this LN realization of the MMT data set. Next, this entire exercise is repeated using the same LN realization, but with $z_{\Delta v}=400 \mathrm{~km} \mathrm{~s}^{-1}$, representing the attempt to correct for quasar systemic redshifts by applying a global velocity shift to all Ly- $\alpha$ emission redshifts.

We use the random simulations as the baseline for comparison, but we are interested primarily in the magnitude and direction of the bias in the ionization rate introduced by uncertainty in quasar redshifts. We define this bias relative to $\log (\Gamma)=$ -11.93, the value of the ionization rate we derive from this realization of this model using the quasar redshifts that define the quasar position in the model spectra. For
the ten calculations with no $z_{\Delta v}$ correction to the transformed quasar redshifts applied, we find that the mean ionization rate is larger than $\log (\Gamma)=-11.93$ by a factor of 3.6 , or $2.1 \sigma$. The results are listed in Table 5.5 and shown in a histogram in Figure 5.18. This shift occurs in the direction expected. If quasar redshifts are systematically redshifted from Ly- $\alpha$, the extent of the proximity effect is underestimated and the ionizing background is overestimated. Applying the $z_{\Delta v}$ correction to the transformed quasar redshifts, the ionization rates derived are systematically shifted from that derived using the true quasar redshifts, shown by the arrow at $\log (\Gamma)=-11.93$ above. The mean of these ten calculations is shifted by a factor of 1.8 from this result, $1.8 \sigma$. These results are themselves a factor of two different from one another, reproducing the shift in $\Gamma$ measured from the analysis of the MMT data when systemic redshifts are used if possible and $400 \mathrm{~km} \mathrm{~s}^{-1}$ is added to Ly- $\alpha$ redshifts otherwise (Scott et al. 2000b). This experiment emphasizes that the systemic redshift correction is an important one to the proximity effect analysis, but that applying a single global redshift correction may still in fact lead to an overestimation of the ionizing background.

### 5.3 Summary and Future Work

We confirm BD97 in finding that a lognormal model for cosmological density and velocity fields can reproduce the global properties of the Ly- $\alpha$ forest such as the mean flux decrement the cumulative flux decrement distribution and Ly- $\alpha$ absorption line statistics quite well. Reproduction of more detailed flux statistics such as the differential flux distribution will require models such as those discussed by Viel et al. (2002) in which baryon densities are derived from evolved dark matter density fields. For the purposes of investigating the absorption features of the regions near quasars, however, we find the lognormal models to be sufficient.

In both types of LN simulations we perform, the deficit of absorption lines in the
simulated spectra are a reasonable match to the deficits observed in the data. The largest discrepancies with the data in terms of the line deficits within $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ of the quasars are seen in the low luminosity quasar subsample, in the sense that the simulations in which quasars are placed in random positions in the density field tend to produce line deficits larger than are observed in the data and the simulations in which quasars are placed in positions corresponding to $3 \sigma$ overdensities tend to produce smaller line deficits than observed.

In the future, we will explore models which correlate the overdensities in which quasars reside with their luminosity to investigate whether or not this brings better agreement with the data. Also, we will investigate curve of growth effects and further investigate the impact of the clustering of material in the vicinity of quasars by adjusting the quasar luminosities input into the simulations to determine how this affects the line deficits as a function of distance from the quasars.

The values of $\Gamma$ and $f_{\Gamma}$ derived from a maximum likelihood analysis of the absorption line distribution near the quasars in the MMT data are in good agreement with that required to match the flux decrement distribution in the LN models to the MMT data, demonstrating an overall self-consistency in the models and a reliability in the maximum likelihood method of deriving the background from absorption lines.

However, the ten realizations of both the random and the high density simulations give a large spread in the ionization rates one measures from the maximum likelihood analysis on the absorption lines in the model spectra. Solving for single value of $\Gamma$ over the redshift range $z=1.9-4.1$, the results from the random simulations underestimate the simulation input at the median redshift, by a factor of 1.7 , or $1.3 \sigma$. It is not immediately clear why this should be the case. A possible explanation is that a single-valued ionization rate over this redshift range is simply not a good assumption. Indeed, the simulation input ionization rates are a factor of 3.8 lower at $z=4.1$ than they are at $z=1.9$. Solving instead for a factor by which the HM96 ionization rates given in Equation 5.11 are scaled, the results from the maximum
likelihood analysis on these simulations agree very well with the simulation inputs. The mean of all ten $f_{\Gamma}$ derived from these simulations overestimates than the input value by only $5 \%$.

The simulations in which quasars are placed in $3 \sigma$ overdensities in the density fields systematically suppress the proximity effect signature seen in the line deficit with distance from the quasar and cause the absorption line based method to overestimate the input ionizing background. These high density simulations also result in a larger spread of the maximum likelihood ionization rates measured from the simulated spectra. Figure 5.17 demonstrates that the $f_{\Gamma}$ derived from every realization is an overestimate of the input. The mean of all ten realizations is 3.2 times larger than the input value, though because of the large spread in $f_{\Gamma}$ derived from the simulations, this is formally $\sim 1 \sigma$ larger than the input. This factor is consistent with the prediction that clustering of $\mathrm{Ly}-\alpha$ absorption around quasars could cause a factor of 3 overestimation of the mean background (Loeb \& Eisenstein 1995). The maximum likelihood solution for a single $\Gamma$ also gives values larger than those input into the simulations. The mean of all ten realizations is $47 \%$ larger than the input ionization rate at the median redshift.

The relative uncertainties in the maximum likelihood solutions indicate how well the assumed likelihood function represents the absorption line distribution. We expect these to be lower for the random simulations than for the high density simulations because the likelihood function makes no accommodation for clustering of matter, and a higher incidence of absorption, near quasars. The relative uncertainties of the maximum likelihood solutions for both $\Gamma$ and $f_{\Gamma}$ from the random simulations are in better agreement with those derived from the maximum likelihood analysis on the data itself. The uncertainty in the single ionization rate solution is $+58 \% /-32 \%$ for the data and $+45 \% /-27 \%$ for the random simulations while it is $+81 \% /-36 \%$ for the high density simulations. Likewise, for the $f_{\Gamma}$ solution, we find uncertainty of $+54 \% /-$ $29 \%$ for the data, $+52 \% /-30 \%$ for the random simulations, and $+90 \% /-39 \%$ for the
high density simulations.
It is perhaps not surprising that we should find better agreement between the data and the random simulations than between the data and the high density simulations given that we have removed objects from the data sample which show metal absorption features within $5000 \mathrm{~km} \mathrm{~s}^{-1}$ of the quasar emission. From a sample of ten quasars with associated C IV absorption at $0.15<z<0.65$, Ellingson et al. (1994) found that these quasars also show a higher incidence of galaxies within 35 kpc of the line of sight than is seen in a control sample of quasars, suggesting that galactic environment determines the presence of associated absorption. It is possible that we are therefore removing the very objects which would be expected to show excess absorption due to material clustered around the quasar. However, observations of the metallicities and ionization states of associated absorbers (Papovich et al. 2000, Hamann et al. 2001) as well as their time variability (Hamann, Barlow, \& Junkkarinen 1997, Ganguly et al. 2001) and rate of incidence in steep-spectrum and lobe-dominated radio loud quasars (Foltz et al. 1986, Baker et al. 2002) suggest that this absorption arises from material intrinsic to quasars rather than that comprising the large scale galactic environments of quasars (see also Wold et al. 2000). As our high density simulations attempt to treat the latter case, and because in any one object we generally do not know the source of the associated absorption, omitting quasars which show this absorption from our comparisons with the simulations is somewhat justified.

Therefore, if quasars inhabit random positions in the line of sight distribution of mass, measurements of the ionizing background are likely to reflect the true metagalactic ionization rates. If, more realistically, quasars reside preferentially in high density regions as predicted by hierarchical structure formation scenarios, the ionization rate measured from the proximity effect in observed quasar spectra may be overestimated by up to a factor of three.

We demonstrate that the observed velocity differences between quasar redshifts
determined from the Ly- $\alpha$ emission line and systemic redshifts from [OIII] $\lambda 5007$ may lead to an overestimation of the metagalactic ionization rate by up to a factor of 3.6 if uncorrected. Applying a mean global velocity shift to all Ly- $\alpha$ emission redshifts mitigates this to some extent, but the resulting measurement is still likely to be an overestimate of the true ionization rate. It is therefore desirable to redshifts based on [OIII] $\lambda 5007$ or another reliable indicator of the quasar systemic redshift whenever possible, especially given that clustering of matter around quasars may already introduce a bias in the result of roughly this order. If the proximity effect measurements of the mean background at $z \sim 2-3$ are indeed a factor of three larger than the true background, this places them distinctly at odds with model estimates which incorporate a contribution from star-forming galaxies with high UV escape fractions at these redshfits (Bianchi, Cristini, \& Kim 2001).

### 5.3.1 Measurement of UV Background from Mean Flux

Above, we demonstrated that the methods using absorption line deficits near quasars to measure the ionizing background are reliable, but large uncertainties in the maximum likelihood solutions do result from this treatment. We seek to develop a process for measuring the background using flux statistics rather than absorption lines. The advantages of using a method based on flux rather than upon identified absorption lines above some equivalent width threshold are: (1) all of the information contained in the spectrum may be used as there is no threshold analogous to the equivalent width threshold for which information is discarded, thus, there are many more points to be used in a solution; (2) the problems associated with identifying and fitting absorption lines, especially in moderate resolution spectra, may be avoided; (3) an average Ly- $\alpha$ forest transmission baseline must be defined, but there is no need to fit parameters describing the line distribution in the Ly- $\alpha$ forest such as the redshift dis-
tribution parameter $\gamma$, the column density distribution parameter ${ }^{2}, \beta$, or the Doppler parameter, and (4) concerns about the curve of growth may be avoided, and we may avoid the assumption that the column density of a particular absorption line responds in a linear fashion to the ionizing flux.

We briefly outline a method to be refined and used on the data and simulated quasar spectra in future work. We start by assuming that the mean optical depth is proportional to $(1+\omega)^{-1}$, which is true for the high ionization limit:

$$
\begin{equation*}
\tau=\frac{\pi e^{2}}{m_{e} c} f_{\mathrm{Ly} \alpha} \lambda_{\mathrm{Ly} \alpha} H^{-1}(z) \frac{1.16 n_{H}^{2} \alpha(T)}{\Gamma} \tag{5.13}
\end{equation*}
$$

where $f_{\mathrm{Ly} \alpha}$ and $\lambda_{\mathrm{Lya}}$ are the $\mathrm{Ly}-\alpha$ oscillator strength and wavelength and $\alpha(T)$ is the $\mathrm{H}^{+}$recombination rate (Weinberg et al. 1997). In the Ly- $\alpha$ forest, $\Gamma$ equals the contribution from the background alone, $\Gamma_{b g}$, but in the proximity effect regions near quasars, $\Gamma$ becomes $\Gamma_{b g}+\Gamma_{q}$, so $\tau_{p e}=\tau_{\mathrm{Lya} \alpha} \frac{\Gamma_{b g}}{\Gamma_{b g}+\Gamma_{q}}=\tau_{\mathrm{Lya}} \frac{1}{1+\omega}$. The high ionization assumption does not seem unwarranted in the absence of clustering, given that it is frequently made in the literature to describe the mean flux in the Ly- $\alpha$ forest, and the proximity regions of quasars should only be more highly ionized than the forest. If, however, strong absorption features cluster around quasars due to the matter overdensities in which they reside, this assumption becomes less valid.

We may perform this analysis on all the flux points binned in $\omega$, analogous to the BDO treatment for absorption lines; or we may do a maximum likelihood calculation. We will discuss the binned treatment first.

The analogy to the BDO method for extracting the background from the deficit of absorption lines simply consists of binning all flux points in the parameter $\omega$, calculated by using the redshift of each flux point and the HM96 ionization rate scaled by the factor of 1.43 required to match the mean flux decrements in the MMT and simulated spectra. We seek to find the factor that gives the lowest $\chi^{2}$ between

[^1]the binned flux points and the ionization model:
\[

$$
\begin{equation*}
\langle\mathrm{F}\rangle_{\text {model }}=\left\langle\mathrm{F}>_{0}-\exp \left[f_{c}(1+\omega)\right]\right. \tag{5.14}
\end{equation*}
$$

\]

In this expression, $\left\langle\mathrm{F}>_{0}\right.$ is the normalization, the average flux in the Ly- $\alpha$ forest in the data or the simulation, and $f_{c}$ is a factor we introduce to account for any clustering of absorption around quasars (cf. Pascarelle et al. 2001), or any departures from the high ionization assumption, which includes the assumption of photoionization equilibrium.

We scale the ionization rate given by $f_{\Gamma}$, as in Equation 5.11. We then bin all the flux points in all the quasar spectra in the quantity $\omega$, the ratio of the ionization rate due to the quasar at the position of the absorbing pixel to the ionization rate of the background. The $\chi^{2}$ of these binned flux points with respect to Equation 5.14 is calculated. A search is conducted for the scaling factor, $f_{\Gamma}$, that gives the lowest value of this $\chi^{2}$.

The maximum likelihood calculation consists of finding the average flux and flux variance in $50 \AA$ bins, and calculating the minimum $\chi^{2}$ with respect to the ionization model, the likelihood function is thus

$$
\begin{equation*}
L=\exp \left(\sum_{i} \frac{\left\langle\mathrm{~F}>_{i}-<\mathrm{F}>_{\text {model }}\right.}{\sigma_{i}^{2}}\right) \tag{5.15}
\end{equation*}
$$

where the index $i$ refers to each $50 \AA$ bin, $\langle\mathrm{F}\rangle_{i}$ and $\sigma_{i}^{2}$ are the average and variance of the flux in that bin, and $\langle\mathrm{F}\rangle_{\text {model }}$ is the ionization model in Equation 5.14 above. In practice, we will solve for $\Gamma$ by minimizing $-\log (L)$.

The clustering factor, $f_{c}$ is determined by comparison with the simulations, namely by finding the value of $f_{c}$ for which the $f_{\Gamma}$ input into the simulations is recovered. This will be different, and presumably larger, for the simulations that mimic clustering of matter around quasars by placing them in overdense regions. The clustering factors derived from the random and high density simulations are then applied to the data to derive two values of the scaling factor $f_{\Gamma}$, one for a scenario in which quasars occupy
random positions in the large scale density distribution and one in which they inhabit regions of $3 \sigma$ overdensity. Figure 5.19 demonstrates this technique. In the $\mathrm{Ly}-\alpha$ forest, there exist a number of bins in which the flux is low, $\langle\mathrm{F}\rangle \lesssim 0.6$, whereas in the proximity region $(\log (\omega) \gtrsim-1)$ there exist no points at these low flux levels. The left panels correspond to the solutions for $f_{c}$, for each type of simulation, that gives the input scaling factor, $f_{\Gamma}=1.43$. The random simulations give $f_{c}=1.17$ and the high density simulations give $f_{c}=1.60$. On the right are the maximum likelihood values of $f_{\Gamma}$ derived from the data with these two values of the clustering factor applied. These solutions are $f_{\Gamma}=0.92_{-0.25}^{+0.38}$ for $f_{c}=1.17$ and $f_{\Gamma}=4.85_{-1.79}^{+3.53}$ for $f_{c}=1.60$. The relative errors in these solutions are only marginally lower than those that arise from the absorption line analysis, so this flux-based method will require further refinement.

A method such as this one, which is based on flux in the spectrum rather than on absorption lines, is particularly sensitive to the placement of the quasar continuum, but should be useful for extending proximity effect measurements of the UV background to redshifts greater than 4.5 (Songaila \& Cowie 2002) where the standard absorption line analysis becomes impossible due to the low overall transmission of the IGM.

Table 5.1: Mean Flux Decrements in Simulated Spectra

| Real. ${ }^{1}$ | Sample | $\Delta z$ | $\langle z\rangle$ | $\Omega_{0}, \Omega_{\Lambda}$ | $\Omega_{6} \mathrm{~h}^{2}$ | $\Gamma_{-12}$ | EOS $^{2}$ | $\mu$ | $\langle D\rangle$ | $\left\langle\mathrm{D}_{0}{ }^{3}\right.$ | $Q(\mathrm{KS})^{4}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| - | 1 | $1.5-2.5$ | 2.29 | $1.0,0.0$ | 0.024 | 1.37 | R97 | 1.03 | 0.155 | 0.154 | 0.72 |
| - | 1 | $1.5-2.5$ | 2.29 | $0.4,0.6$ | 0.024 | 1.37 | R97 | 1.22 | 0.134 | 0.152 | 0.35 |
| - | 2 | $1.5-2.5$ | 2.29 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.65 | 0.135 | 0.148 | 0.92 |
| - | 2 | $2.5-3.5$ | 3.02 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.56 | 0.299 | 0.316 | 0.31 |
| 1 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.128 | 0.129 | 0.72 |
| 1 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.307 | 0.250 | 0.007 |
| 1 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.118 | 0.129 | 0.80 |
| 1 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.327 | 0.250 | 0.03 |
| 2 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.103 | 0.129 | 0.43 |
| 2 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.240 | 0.250 | 0.40 |
| 2 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.102 | 0.129 | 0.11 |
| 2 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.238 | 0.250 | 0.98 |
| 3 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.108 | 0.129 | 0.55 |
| 3 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.253 | 0.250 | 0.46 |
| 3 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.123 | 0.129 | 0.99 |
| 3 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.284 | 0.250 | 0.82 |
| 4 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.106 | 0.129 | 0.77 |
| 4 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.232 | 0.250 | 0.80 |
| 4 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.139 | 0.129 | 0.99 |
| 4 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.253 | 0.250 | 0.99 |
| 5 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.133 | 0.129 | 0.79 |
| 5 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.284 | 0.250 | 0.05 |
| 5 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.136 | 0.129 | 0.99 |
| 5 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.257 | 0.250 | 0.99 |
| 6 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.45 | HG97 | 0.76 | 0.101 | 0.129 | 0.37 |
| 6 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.237 | 0.250 | 0.74 |

Table 5.1: Mean Flux Decrements in Simulated Spectra (Continued)

| Real. ${ }^{1}$ | Sample | $\Delta z$ | $\langle z\rangle$ | $\Omega_{0}, \Omega_{\Lambda}$ | $\Omega_{6} \mathrm{~h}^{2}$ | $\Gamma_{-12}$ | EOS $^{2}$ | $\mu$ | $\langle D\rangle$ | $\langle\mathrm{D}\rangle_{0}{ }^{3}$ | $Q(\mathrm{KS})^{4}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 6 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.117 | 0.129 | 0.46 |
| 6 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.252 | 0.250 | 0.98 |
| 7 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.135 | 0.129 | 0.64 |
| 7 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.278 | 0.250 | 0.03 |
| 7 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.122 | 0.129 | 0.98 |
| 7 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.250 | 0.250 | 0.99 |
| 8 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.125 | 0.129 | 0.66 |
| 8 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.291 | 0.250 | 0.01 |
| 8 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.126 | 0.129 | 0.99 |
| 8 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.277 | 0.250 | 0.93 |
| 9 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.121 | 0.129 | 0.93 |
| 9 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.283 | 0.250 | 0.04 |
| 9 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.112 | 0.129 | 0.29 |
| 9 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.264 | 0.250 | 0.99 |
| 10 | 3 | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.133 | 0.129 | 0.52 |
| 10 | 3 | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.291 | 0.250 | 0.04 |
| 10 | 3 a | $1.5-2.5$ | 2.07 | $0.3,0.7$ | 0.019 | 1.46 | HG97 | 0.76 | 0.130 | 0.129 | 0.99 |
| 10 | 3 a | $2.5-3.5$ | 2.85 | $0.3,0.7$ | 0.019 | 1.35 | HG97 | 0.55 | 0.294 | 0.250 | 0.65 |

Table 5.1: Mean Flux Decrements in Simulated Spectra
(Continued)

| Real. ${ }^{1}$ | Sample | $\Delta z$ | $\langle z\rangle$ | $\Omega_{0}, \Omega_{\Lambda}$ | $\Omega_{b} \mathrm{~h}^{2}$ | $\Gamma_{-12}$ | EOS $^{2}$ | $\mu$ | $<D>$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |

Sample:
(1) Simulation of Keck data set in R97
(2) Simulation of MMT data set at Keck resolution and S/N
(3) Simulation of MMT data set at MMT resolution and S/N

Quasars in random positions in density fields
(3a) Simulation of MMT data set at MMT resolution and $\mathrm{S} / \mathrm{N}$
Quasars in high density regions
${ }^{1}$ Realization of LN simulation
${ }^{2}$ Density-temperature relation from Figure 7 of R97 or from HG97
${ }^{3}$ Comparison mean decrement:
Sample 1- R97 simulations
Sample 2- Keck data in R97
Samples 3 and 3a- MMT data in Scott et al. 2000a
${ }^{4} \mathrm{KS}$ probability of cumulative flux decrement distribution of Sample with respect to comparison sample in Col. 9
${ }^{5}$ See their Figure 7

Table 5.2: Line Statistics

| Realization | Sample | $W$ limit | $\mathcal{A}_{1}$ | $\gamma$ |
| :---: | :---: | :---: | :---: | :---: |
| - | 1 a | var. | $1.21 \pm 0.20$ | - |
| - | 1b | var. | $1.00 \pm 0.15$ | - |
| - | 1a | 0.32 | $1.67 \pm 0.29$ | 7.57 |
| - | 1b | 0.32 | $1.53 \pm 0.21$ | 8.53 |
| - | 1a | 0.16 | $1.32 \pm 0.27$ | 21.3 |
| - | 1b | 0.16 | $1.07 \pm 0.19$ | 27.3 |
| 1 | 2a | var. | $1.24 \pm 0.46$ | - |
| 1 | 2b | var. | $0.81 \pm 0.30$ | - |
| 1 | 2a | 0.32 | $2.16 \pm 0.68$ | 4.91 |
| 1 | 2b | 0.32 | $1.77 \pm 0.43$ | 7.67 |
| 1 | 2a | 0.16 | $1.51 \pm 0.54$ | 19.8 |
| 1 | 2b | 0.16 | $1.04 \pm 0.35$ | 33.4 |
| 1 | 3a | var. | $1.82 \pm 0.57$ | - |
| 1 | 3b | var. | $1.25 \pm 0.36$ | - |
| 1 | 3 a | 0.32 | $2.35 \pm 0.74$ | 3.24 |
| 1 | 3b | 0.32 | $1.49 \pm 0.47$ | 9.30 |
| 1 | 3a | 0.16 | $1.68 \pm 0.61$ | 12.7 |
| 1 | 3b | 0.16 | $1.41 \pm 0.38$ | 17.3 |
| 2 | 2a | var. | $1.30 \pm 0.50$ | - |
| 2 | 2b | var. | $1.23 \pm 0.32$ | - |
| 2 | 2a | 0.32 | $2.01 \pm 0.78$ | 4.46 |
| 2 | 2b | 0.32 | $1.87 \pm 0.49$ | 5.31 |
| 2 | 2a | 0.16 | $1.44 \pm 0.61$ | 17.3 |
| 2 | 2b | 0.16 | $1.49 \pm 0.38$ | 15.5 |
| 2 | 3a | var. | $1.16 \pm 0.58$ | - |
| 2 | 3b | var. | $1.21 \pm 0.37$ | - |
| 2 | 3a | 0.32 | $1.12 \pm 0.77$ | 14.0 |
| 2 | 3 b | 0.32 | $1.32 \pm 0.49$ | 10.4 |
| 2 | 3a | 0.16 | $0.81 \pm 0.67$ | 31.2 |
| 2 | 3b | 0.16 | $1.13 \pm 0.43$ | 19.8 |
| 3 | 2a | var. | $1.52 \pm 0.51$ | - |
| 3 | 2 b | var. | $1.22 \pm 0.32$ | - |
| 3 | 2a | 0.32 | $2.25 \pm 0.77$ | 3.35 |
| 3 | 2b | 0.32 | $2.14 \pm 0.48$ | 3.79 |
| 3 | 2a | 0.16 | $1.82 \pm 0.61$ | 10.6 |
| 3 | 2 b | 0.16 | $1.52 \pm 0.39$ | 14.8 |
| 3 | 3a | var. | $1.47 \pm 0.56$ | - |
| 3 | 3 b | var. | $1.20 \pm 0.36$ | - |

Table 5.2: Line Statistics (Continued)

| Realization | Sample | $W$ limit | $\mathcal{A}$ | $\gamma$ |
| :---: | :---: | :---: | :---: | :---: |
| 3 | 3a | 0.32 | $1.86 \pm 0.73$ | 6.14 |
| 3 | 3b | 0.32 | $1.42 \pm 0.47$ | 10.0 |
| 3 | 3 a | 0.16 | $1.20 \pm 0.65$ | 19.9 |
| 3 | 3b | 0.16 | $1.08 \pm 0.41$ | 22.9 |
| 4 | 2a | var. | $1.65 \pm 0.51$ | - |
| 4 | 2b | var. | $1.27 \pm 0.32$ | - |
| 4 | 2a | 0.32 | $2.81 \pm 0.76$ | 1.70 |
| 4 | 2b | 0.32 | $2.31 \pm 0.48$ | 3.09 |
| 4 | 2a | 0.16 | $1.51 \pm 0.54$ | 19.8 |
| 4 | 2b | 0.16 | $1.04 \pm 0.35$ | 33.4 |
| 4 | 3a | var. | $1.47 \pm 0.57$ | - |
| 4 | 3b | var. | $1.18 \pm 0.36$ | - |
| 4 | 3a | 0.32 | $1.78 \pm 0.72$ | 6.91 |
| 4 | 3b | 0.32 | $1.22 \pm 0.46$ | 13.3 |
| 4 | 3a | 0.16 | $1.05 \pm 0.66$ | 9.41 |
| 4 | 3b | 0.16 | $0.85 \pm 0.42$ | 18.3 |
| 5 | 2a | var. | $1.43 \pm 0.51$ | - |
| 5 | 2b | var. | $1.17 \pm 0.32$ | - |
| 5 | 2a | 0.32 | $2.38 \pm 0.76$ | 2.94 |
| 5 | 2b | 0.32 | $2.17 \pm 0.48$ | 3.61 |
| 5 | 2a | 0.16 | $1.68 \pm 0.61$ | 12.7 |
| 5 | 2b | 0.16 | $1.41 \pm 0.38$ | 17.3 |
| 5 | 3a | var. | $1.63 \pm 0.57$ | - |
| 5 | 3b | var. | $1.08 \pm 0.36$ | - |
| 5 | 3a | 0.32 | $2.19 \pm 0.74$ | 3.96 |
| 5 | 3b | 0.32 | $1.37 \pm 0.47$ | 10.7 |
| 5 | 3a | 0.16 | $1.33 \pm 0.65$ | 17.3 |
| 5 | 3b | 0.16 | $0.86 \pm 0.41$ | 30.9 |
| 6 | 2a | var. | $1.43 \pm 0.51$ | - |
| 6 | 2b | var. | $1.17 \pm 0.32$ | - |
| 6 | 2a | 0.32 | $2.38 \pm 0.76$ | 2.94 |
| 6 | 2 b | 0.32 | $2.17 \pm 0.48$ | 3.61 |
| 6 | 2a | 0.16 | $1.68 \pm 0.61$ | 12.7 |
| 6 | 2 b | 0.16 | $1.41 \pm 0.38$ | 17.3 |
| 6 | 3a | var. | $0.86 \pm 0.56$ | - |
| 6 | 3b | var. | $0.95 \pm 0.36$ | - |
| 6 | 3 a | 0.32 | $0.85 \pm 0.74$ | 21.1 |
| 6 | 3 b | 0.32 | $1.05 \pm 0.47$ | 16.0 |

Table 5.2: Line Statistics (Continued)

| Realization | Sample | $W$ limit | $\mathcal{A}$, | $\gamma$ |
| :---: | :---: | :---: | :---: | :---: |
| 6 | 3a | 0.16 | $0.97 \pm 0.66$ | 26.2 |
| 6 | 3b | 0.16 | $0.91 \pm 0.42$ | 27.8 |
| 7 | 2a | var. | $1.00 \pm 0.45$ | - |
| 7 | 2 b | var. | $0.76 \pm 0.29$ | - |
| 7 | 2a | 0.32 | $2.07 \pm 0.66$ | 5.69 |
| 7 | 2b | 0.32 | $1.71 \pm 0.43$ | 8.41 |
| 7 | 2a | 0.16 | $1.09 \pm 0.54$ | 33.8 |
| 7 | 2b | 0.16 | $0.99 \pm 0.35$ | 35.6 |
| 7 | 3a | var. | $1.36 \pm 0.56$ | - |
| 7 | 3 b | var. | $1.18 \pm 0.36$ | - |
| 7 | 3 a | 0.32 | $1.64 \pm 0.74$ | 7.96 |
| 7 | 3b | 0.32 | $1.63 \pm 0.47$ | 7.84 |
| 7 | 3a | 0.16 | $1.32 \pm 0.65$ | 17.1 |
| 7 | 3b | 0.16 | $1.07 \pm 0.42$ | 22.7 |
| 8 | 2a | var. | $1.28 \pm 0.46$ | - |
| 8 | 2b | var. | $0.80 \pm 0.30$ | - |
| 8 | 2a | 0.32 | $2.07 \pm 0.67$ | 5.52 |
| 8 | 2b | 0.32 | $1.88 \pm 0.43$ | 6.67 |
| 8 | 2a | 0.16 | $1.72 \pm 0.55$ | 14.5 |
| 8 | 2 b | 0.16 | $1.08 \pm 0.35$ | 31.0 |
| 8 | 3a | var. | $1.57 \pm 0.56$ | - |
| 8 | 3 b | var. | $1.16 \pm 0.36$ | - |
| 8 | 3 a | 0.32 | $2.24 \pm 0.75$ | 3.65 |
| 8 | 3b | 0.32 | $1.88 \pm 0.48$ | 5.42 |
| 8 | 3 a | 0.16 | $1.68 \pm 0.65$ | 11.5 |
| 8 | 3b | 0.16 | $1.32 \pm 0.41$ | 16.5 |
| 9 | 2 a | var. | $1.19 \pm 0.47$ | - |
| 9 | 2 b | var. | $0.84 \pm 0.30$ | - |
| 9 | 2a | 0.32 | $1.65 \pm 0.68$ | 9.19 |
| 9 | 2 b | 0.32 | $1.46 \pm 0.44$ | 10.9 |
| 9 | 2a | 0.16 | $1.42 \pm 0.56$ | 20.8 |
| 9 | 2 b | 0.16 | $0.99 \pm 0.35$ | 34.8 |
| 9 | 3a | var. | $1.33 \pm 0.56$ | - |
| 9 | 3 b | var. | $1.13 \pm 0.36$ | - |
| 9 | 3 a | 0.32 | $1.45 \pm 0.72$ | 10.6 |
| 9 | 3 b | 0.32 | $1.41 \pm 0.46$ | 10.5 |
| 9 | 3 a | 0.16 | $1.28 \pm 0.65$ | 18.3 |
| 9 | 3b | 0.16 | $1.00 \pm 0.41$ | 24.8 |

Table 5.2: Line Statistics (Continued)

| Realization | Sample | $W$ limit | $\mathcal{A}_{1}$ | $\gamma$ |
| :---: | :---: | :--- | :---: | :--- |
| 10 | 2a | var. | $0.83 \pm 0.46$ | - |
| 10 | 2b | var. | $0.77 \pm 0.30$ | - |
| 10 | 2a | 0.32 | $1.97 \pm 0.67$ | 6.25 |
| 10 | 2b | 0.32 | $1.65 \pm 0.43$ | 8.76 |
| 10 | 2a | 0.16 | $0.79 \pm 0.54$ | 48.4 |
| 10 | 2b | 0.16 | $0.83 \pm 0.35$ | 43.0 |
| 10 | 3a | var. | $1.63 \pm 0.57$ | - |
| 10 | 3b | var. | $1.37 \pm 0.37$ | - |
| 10 | 3a | 0.32 | $1.99 \pm 0.72$ | 5.39 |
| 10 | 3b | 0.32 | $1.65 \pm 0.47$ | 7.59 |
| 10 | 3a | 0.16 | $1.71 \pm 0.65$ | 10.7 |
| 10 | 3b | 0.16 | $1.26 \pm 0.42$ | 17.7 |

Sample:
1- MMT data
(a) Ly - $\alpha$ forest
(b) Ly- $\alpha$ forest + proximity effect region

2- realization of LN model, random simulations
(a) $\mathrm{Ly}-\alpha$ forest
(b) Ly- $\alpha$ forest + proximity effect region

3- realization of LN model, high density simulations
(a) $\mathrm{Ly}-\alpha$ forest
(b) Ly- $\alpha$ forest + proximity effect region

Table 5.3: Mean Ly- $\alpha$ Optical Depth versus Redshift

| Realization | Sample | A | $\gamma$ |
| :---: | :---: | :---: | :---: |
| - | 1 a | $0.0085 \pm 0.00019$ | $1.41 \pm 0.018$ |
| - | 1b | $0.022 \pm 0.00032$ | $0.24 \pm 0.012$ |
| 1 | 2a | $0.0030 \pm 0.000075$ | $2.34 \pm 0.020$ |
| 1 | 2b | $0.0056 \pm 0.00012$ | $1.77 \pm 0.017$ |
| 1 | 3a | $0.0020 \pm 0.000053$ | $2.40 \pm 0.021$ |
| 1 | 3b | $0.0032 \pm 0.000067$ | $1.96 \pm 0.016$ |
| 2 | 2a | $0.0038 \pm 0.000088$ | $2.93 \pm 0.018$ |
| 2 | 2b | $0.0043 \pm 0.000078$ | $1.77 \pm 0.014$ |
| 2 | 3a | $0.0032 \pm 0.000082$ | $2.00 \pm 0.020$ |
| 2 | 3b | $0.0047 \pm 0.000095$ | $1.64 \pm 0.015$ |
| 3 | 2a | $0.0039 \pm 0.000092$ | $1.95 \pm 0.019$ |
| 3 | 2b | $0.0055 \pm 0.00010$ | $1.59 \pm 0.015$ |
| 3 | 3a | $0.0029 \pm 0.000080$ | $2.13 \pm 0.021$ |
| 3 | 3b | $0.0047 \pm 0.00010$ | $1.68 \pm 0.017$ |
| 4 | 2a | $0.0025 \pm 0.000058$ | $2.26 \pm 0.018$ |
| 4 | 2b | $0.0043 \pm 0.000081$ | $1.77 \pm 0.014$ |
| 4 | 3a | $0.0045 \pm 0.00013$ | $1.77 \pm 0.023$ |
| 4 | 3b | $0.0064 \pm 0.00014$ | $1.44 \pm 0.017$ |
| 5 | 2a | $0.0042 \pm 0.00011$ | $2.07 \pm 0.023$ |
| 5 | 2b | $0.0062 \pm 0.00013$ | $1.69 \pm 0.017$ |
| 5 | 3a | $0.0031 \pm 0.000082$ | $2.09 \pm 0.021$ |
| 5 | 3b | $0.0069 \pm 0.00014$ | $1.36 \pm 0.016$ |
| 6 | 2a | $0.0029 \pm 0.000072$ | $2.16 \pm 0.019$ |
| 6 | 2 b | $0.0046 \pm 0.000086$ | $1.71 \pm 0.014$ |
| 6 | 3a | $0.0085 \pm 0.00022$ | $1.26 \pm 0.022$ |
| 6 | 3b | $0.0093 \pm 0.00019$ | $1.14 \pm 0.017$ |
| 7 | 2a | $0.0043 \pm 0.00012$ | $2.06 \pm 0.023$ |
| 7 | 2b | $0.0064 \pm 0.00013$ | $1.66 \pm 0.017$ |
| 7 | 3a | $0.0026 \pm 0.000072$ | $2.20 \pm 0.002$ |
| 7 | 3b | $0.0050 \pm 0.00011$ | $1.63 \pm 0.017$ |
| 8 | 2a | $0.0035 \pm 0.000093$ | $2.22 \pm 0.021$ |
| 8 | 2b | $0.0061 \pm 0.00013$ | $1.69 \pm 0.017$ |
| 8 | 3 a | $0.0021 \pm 0.000052$ | $2.33 \pm 0.020$ |
| 8 | 3b | $0.0038 \pm 0.000074$ | $1.77 \pm 0.015$ |
| 9 | 2a | $0.0042 \pm 0.00011$ | $2.05 \pm 0.022$ |
| 9 | 2 b | $0.0064 \pm 0.00014$ | $1.65 \pm 0.017$ |
| 9 | 3a | $0.0027 \pm 0.000078$ | $2.19 \pm 0.023$ |
| 9 | 3b | $0.0038 \pm 0.000083$ | $1.85 \pm 0.017$ |

Table 5.3: Mean Ly- $\alpha$ Optical Depth versus Redshift (Continued)

| Realization | Sample | $A$ | $\gamma$ |
| :---: | :---: | :--- | :---: |
| 10 | 2 a | $0.0030 \pm 0.000084$ | $2.32 \pm 0.022$ |
| 10 | 2b | $0.0053 \pm 0.00011$ | $1.82 \pm 0.018$ |
| 10 | 3a | $0.0037 \pm 0.00010$ | $1.93 \pm 0.022$ |
| 10 | 3 b | $0.0053 \pm 0.00011$ | $1.57 \pm 0.017$ |

Sample:
1- MMT data
(a) Ly- $\alpha$ forest
(b) Ly- $\alpha$ forest + proximity effect region

2- realization of LN model, random simulations
(a) $\mathrm{Ly}-\alpha$ forest
(b) Ly- $\alpha$ forest + proximity effect region

3- realization of LN model, high density simulations
(a) $\mathrm{L} y-\alpha$ forest
(b) Ly- $\alpha$ forest + proximity effect region

Table 5.4. Ionization Rates and HM96 Scaling Factors

| Realization | Sample | $\log (\Gamma)$ | $f_{\Gamma}$ |
| :---: | :---: | :---: | :---: |
| - | 1 | $-11.822_{-0.17}^{+0.20}$ | $1.42{ }_{-0.42}^{+0.78}$ |
| 1 | 2 | $-12.10_{-0.14}^{+0.16}$ | $1.49_{-0.48}^{+0.79}$ |
| 1 | 3 | $-11.86_{-0.18}^{+0.20}$ | $2.77_{-1.04}^{+1.89}$ |
| 2 | 2 | $-12.07_{-0.17}^{+0.20}$ | $1.20{ }_{-0.44}$ |
| 2 | 3 | $-11.29_{-0.26}^{+0.33}$ | $8.64{ }_{-3.91}^{+10.0}$ |
| 3 | 2 | $-11.66_{-0.20}^{+0.23}$ | $4.14{ }_{-1.65}^{+3.27}$ |
| 3 | 3 | $-11.84_{-0.24}^{+0.30}$ | $3.35{ }_{-1.56}^{+3.64}$ |
| 4 | 2 | $-12.02_{-0.15}^{+0.18}$ | $1.28_{-0.39}^{+0.66}$ |
| 4 | 3 | $-11.811_{-0.17}^{+0.21}$ | $2.61{ }_{-0.93}^{+1.69}$ |
| 5 | 2 | $-12.19_{-0.14}^{+0.15}$ | $0.80_{-0.23}^{+0.38}$ |
| 5 | 3 | $-11.75_{-0.19}^{+0.22}$ | $2.51{ }_{-0.91}^{+1.62}$ |
| 6 | 2 | $-12.12_{-0.16}^{+0.17}$ | $1.39_{-0.46}^{+0.82}$ |
| 6 | 3 | $-11.50{ }_{-0.27}^{+0.36}$ | $5.39_{-2.64}^{+7.10}$ |
| 7 | 2 | $-12.24_{-0.14}^{+0.27}$ | $0.98{ }_{-0.30}^{-2.51}$ |
| 7 | 3 | $-11.28_{-0.28}^{+0.35}$ | $12.8{ }_{-6.78}^{+20.4}$ |
| 8 | 2 | $-12.11_{-0.14}^{+0.15}$ | $1.16_{-0.34}^{+0.55}$ |
| 8 | 3 | $-11.77_{-0.22}^{+0.26}$ | $3.26{ }_{-1.50}^{+3.08}$ |
| 9 | 2 | $-11.93_{-0.17}^{+0.19}$ | $1.87{ }_{-0.67}^{+1.21}$ |
| 9 | 3 | $-11.866_{-0.21}^{+0.24}$ | $3.03_{-1.27}^{+2.67}$ |
| 10 | 2 | $-12.30_{-0.13}^{+0.13}$ | $0.81{ }_{-0.22}^{+0.34}$ |
| 10 | 3 | $-12.11_{-0.20}^{+0.22}$ | $1.97{ }_{-0.81}^{+1.65}$ |
| Sample: |  |  |  |
| 1- MMT data |  |  |  |
| 2- realization of LN model, random simulation |  |  |  |
| 3 - realization of LN model, high density simulations |  |  |  |

Table 5.5. Ionization Rates after Redshift Transformation

| Realization | $\log (\Gamma)$ | $\log (\Gamma)$ |
| :---: | :---: | :---: |
|  | $z_{\Delta v}=400 \mathrm{~km} \mathrm{~s}^{-1}$ | $z_{\Delta v}=0 \mathrm{~km} \mathrm{~s}^{-1}$ |
| 1 | $-11.58_{-0.23}^{+0.28}$ | $-11.15_{-0.31}^{+0.47}$ |
| 2 | $-11.79_{-0.20}^{+0.24}$ | $-11.56_{-0.21}^{+0.25}$ |
| 3 | $-11.74_{-0.21}^{+0.21}$ | -11.41 |
| 4 | $-11.70_{-0.21}^{+0.25}$ | $-11.46_{-0.24}^{+0.27}$ |
| 5 | $-11.51_{-0.24}^{+0.31}$ | $-11.32_{-0.24}^{+0.29}$ |
| 6 | $-11.59_{-0.23}^{+0.27}$ | $-11.22_{-0.27}^{+0.33}$ |
| 7 | $-11.79_{-0.19}^{+0.23}$ | $-11.59_{-0.24}^{+0.24}$ |
| 8 | $-11.74_{-0.24}^{+0.24}$ | $-11.36_{-0.24}^{+0.31}$ |
| 9 | $-11.75_{-0.19}^{+0.21}$ | $-11.46_{-0.21}^{+0.25}$ |
| 10 | $-11.70_{-0.20}^{+0.33}$ | $-11.40_{-0.23}^{+0.28}$ |



Figure 5.1. N-body and LN dark matter density distributions at $z=100,30,9$, and 2.33


Figure 5.2. Cumulative flux decrement distributions for Keck data (thin solid line) from R97, and for SCDM and $\Lambda$ CDM LN simulations scaled according to R97 (thick solid and dotted lines). Thin dotted line corresponds to the best fit ACDM LN simulation.


Figure 5.3. Cumulative flux decrement distributions for SPH simulations and LN simulations


Figure 5.4. Distributions of hydrogen neutral fraction, HI optical depth, and hydrogen densities for SPH simulations and LN simulations


Figure 5.5. Cumulative flux decrement distributions: (a) Keck data (thin solid line) from R97, and ACDM LN simulation (thick solid line); (b) MMT data (thin solid line) and $\Lambda$ CDM LN simulation (thick solid line)


Figure 5.6. Histogram of mean decrements at $z=1.5-2.5$ and $z=2.5-3.5$ in simulated spectra: (left panel) quasars in random positions in density fields; (right panel) quasars in high density regions, see § 5.2.2; arrows mark $<\mathrm{D}>$ measured from MMT data


Figure 5.7. Differential flux distribution of pixels in the Ly- $\alpha$ forest and proximity effect regions of 500 bootstrap samples of the MMT data (histograms with error bars) and in the simulations (solid triangles): (top panel) quasars placed at random positions in density field; (bottom panel) quasars placed in high density regions (see § 5.2.2)


Figure 5.8. Data (top panels) and simulated spectra (bottom panels) of two sample quasars


Figure 5.9. Left panels: Redshift distribution of absorption lines for data spectra (bold lines) and one realization of simulated (top panel) random and (bottom panel) high density spectra using (top curves) $0.16 \AA$ and (bottom curves) $0.32 \AA$ equivalent width thresholds; Right panels: Comparison of parameter $\gamma$ derived from real and 10 realizations of the simulated (top panel) random and (bottom panel) high density quasar spectra using $0.16 \AA, 0.32 \AA$, and variable equivalent width thresholds


Figure 5.10. Histograms of $\gamma$ in simulations: (top panel) variable equivalent width threshold; (middle panel) lines with $W>0.32 \AA$; (bottom panel) lines with $W>0.16$ $\AA$; arrows mark values found from MMT data


Figure 5.11. Comparison of differential flux distributions for random and high density simulations, numbers indicate flux bin of $x$-axis in Figure 5.7


Figure 5.12. Mean flux in $100 \AA$ bins as a function of redshift. Thick dashed line is the fit to Ly- $\alpha$ forest points ( $\omega<0.1$ ), thin dashed line in top panel is the PRS fit to Ly- $\alpha$ forest points, dotted line is fit to the full redshift range, including the proximity effect regions with $\omega>0.1$ plotted as open squares. Error bar at left denotes average redshift bin size.


Figure 5.13. Deficit of absorption lines with $W>0.16 \AA$ and $W>0.32 \AA$ with respect to Equ. 5.8 as a function of luminosity distance from QSO for high (bold lines) and low luminosity QSOs


Figure 5.14. Histogram of line deficit within $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ for (left panels) high and (right panels) low luminosity quasars in (top panels) random and (bottom panels) high density simulations for lines with $W>0.32 A$ : arrows mark line deficits in MMT data


Figure 5.15. Histogram of line deficit within $2 \mathrm{~h}^{-1} \mathrm{Mpc}$ for (left panels) high and (right panels) low luminosity quasars in (top panels) random and (bottom panels) high density simulations for lines with $W>0.16 \AA$ : arrows mark line deficits in MMT data


Figure 5.16. Maximum likelihood values of $\Gamma$ (points) and $f_{\Gamma}$ (solid curves) for $z=1.9-4.1$ from absorption line solution for lines with $W>0.32 \AA$ in (top panel) random simulations, (middle panel) high density simulations, and in (bottom panel) MMT data; shaded regions delineate $1 \sigma$ uncertainties on $f_{\Gamma}$; dashed black curves in top and middle panels indicate the photoionization rates input into simulations, $f_{\Gamma}=1.43$, chosen to match the flux decrements in the Ly- $\alpha$ forest data


Figure 5.17. Histograms of (top panels) $\log (\Gamma)$ and (bottom panels) $f_{\Gamma}$ in (left panels) random and (right panels) high density simulations; black arrows mark the values input into simulations, chosen to match flux decrements in the $\mathrm{Ly}-\alpha$ forest data; dotted arrows mark values measured from maximum likelihood analysis on the MMT data


Figure 5.18. (solid line) Histogram $\log (\Gamma)$ derived from ten realizations of the redshift transformation described in Equation 5.12 with $z_{\Delta v}=400 \mathrm{~km} \mathrm{~s}^{-1}$, (dashed line) same as solid line, but $z_{\Delta v}=0 \mathrm{~km} \mathrm{~s}^{-1}$; the arrow denotes the value derived from the simulation using the input quasar redshifts


Figure 5.19. Mean flux in 50 A bins as a function of $\omega$ with maximum likelihood solution to Equation 5.14, $z=1.7-4$.

Appendix A
Figure 2.2 (Continued)
smoothed 50 EW limit ( $\lambda$ )

relative flux ( $f_{\sim}$ )


smoothed so EW limit (A)

relative flux ( $t_{*}$ )



relative flux ( $\mathrm{l}_{*}$ )







smoothed 50 EW limit (A)

relative flux ( $\left(I_{v}\right)$









relative flux ( $p_{v}$ )




smoothed 5aEW limat (A)

relative flux ( 1. )

smoothed 60EW limit (A)






smoothed 50 EW IImit (A)


## Appendix B <br> Line Lists and Identifications for MMT QSO Spectra

|  |  | 017．0干061 7 |  | \＆ |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 0LI0干09L 1 | $600 \mp 68$ | ZZ |
|  |  | $0170 \mp 078.7$ | IIOFIE9ICE | 12 |
| LTVLE $\%=z \angle 801 Y$ I $\Lambda 0$ |  |  |  |  |
|  |  | $0 \pm 80 \mp 00 \sigma^{\circ} \mathrm{Z}$ |  | 07 |
|  |  | 072\％0才018 ${ }^{\circ}$ | ZI＇0干Iて＇I6DE | 6I |
| $88609^{\prime} \mathrm{I}=z$ VEEIY ID |  | 0z\％0干010\％ | カ・0干1\＆て8も¢ | 8I |
|  |  | 0870 0 OLE $¢$ |  | LI |
|  | $8 \angle E L E \cdot 7=z \delta^{\prime} \delta_{\mathrm{I}}$ | $07 \%^{\circ} 0 \mp 0 z \varepsilon^{\circ} \mathrm{E}$ | 01．0干9¢ 09才¢ | 91 |
|  |  | 012．1干089 2 | $68.0 \mp 198 ¢ ¢ ¢ ¢$ | GI |
|  |  | $0 \pm 90$ ¢0ヶ0 $0^{\circ}$ | 8907\％I＇ちちゃを | bl |
|  |  | 0280干0切0 | 910干09 1 ¢もE | \＆I |
|  |  | $08 \chi^{\prime}$ IF0LL | bc．0干E\＆ $68 \pm ¢$ | ZI |
| Z90EI＇L＝z 8091Y IIP3 |  |  |  |  |
| z80ャ8＇I＝z 90ZIY III！S | $688 \mathrm{I} 8^{\circ} \mathrm{I}=z{ }^{\text {o }} \mathrm{K}_{\mathrm{T}}$ | $0880 \mp 080 \cdot 8$ | b「0干98．97ヵ¢ | II |
|  |  | 0680 0 ¢071＇I | 9Z＇0干LZとZも¢ | 0I |
|  |  | $0080 \mp 02 \% \%$ |  | 6 |
|  |  | $068^{\circ} 0 \mp 078^{\circ} 7$ | $8 \varepsilon^{\circ} 0 \mp 88^{\circ} \angle 8 \varepsilon \varepsilon$ | 8 |
|  | 99658 $1=z 007$ IY IN | 008．0干0bc 6 | $28^{\circ} 0 \times 8 \mathrm{D}^{\circ} \mathrm{E} 8 \mathrm{E}$ ¢ | 2 |
|  | $0882 Z \cdot \zeta=z g \kappa^{\prime} \mathrm{T}$ | 06\％ 0 ¢088＇ 1 | 8107¢9＇z9E¢ | 9 |
|  |  | 088．0708 ${ }^{\circ} \mathrm{Z}$ | Iて．0干87＇9EEE | c |
|  |  |  |  | ■ |
| $69609 \cdot \mathrm{I}=z 09 Z 1 \mathrm{Y}$ II！S | DDEE0 $\square^{\circ}=z$ E80IT IIN | $079 \cdot 0 \mp 09 \angle \varepsilon$ | 8Z0干I\＆ 68 Z | $\varepsilon$ |
|  |  | $018.0 \mp 090 \%$ | LZ＇0干60．92\％ | 7 |
|  |  | $016.0 \mp 027.8$ | ع¢ $0 \mp 8 \mathrm{~F}^{\circ} \mathrm{ELZE}$ | I |
| $070+9000$ O |  |  |  |  |
| ${ }^{\text {a }}$ I ${ }^{\text {rimissod }}$ | ио！реэу！ | （y）${ }^{\mathrm{r}} \mathrm{M}$ | ${ }^{\text {sq9 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 24 | $3550.42 \pm 0.20$ | $1.790 \pm 0.240$ |  |  |
| 25 | $3558.62 \pm 0.19$ | $0.660 \pm 0.400$ |  |  |
| 26 | $3561.34 \pm 0.36$ | $1.660 \pm 0.700$ | AlII $\lambda 1670$ | $z=1.13153$ |
|  |  |  |  |  |
| 27 | $3564.21 \pm 0.15$ | $0.790 \pm 0.350$ |  |  |
| 28 | $3567.65 \pm 0.17$ | $2.170 \pm 0.240$ | NV $\lambda 1238$ | $z=1.87988$ |
| 29 | $3579.26 \pm 0.10$ | $0.440 \pm 0.140$ | NV $\lambda 1242$ | $z=1.87999$ |
| SiII $\lambda 1260 \quad z=1.83973$ |  |  |  |  |
| 30 | $3582.31 \pm 1.52$ | $1.100 \pm 0.560$ |  |  |
| 31 | $3588.95 \pm 0.20$ | $0.960 \pm 0.200$ |  |  |
| 32 | $3600.75 \pm 0.69$ | $1.100 \pm 0.560$ |  |  |
| 33 | $3603.64 \pm 0.22$ | $0.960 \pm 0.450$ |  |  |
| 34 | $3637.20 \pm 0.47$ | $1.580 \pm 0.430$ | SiIV $\lambda 1393$ | $z=1.60935$ |
| 35 | $3642.60 \pm 0.16$ | $0.760 \pm 0.140$ |  | SiII $\lambda 1190 \quad z=2.05540$ |
| 36 | $3649.77 \pm 0.22$ | $0.840 \pm 0.160$ |  |  |
| 37 | $3655.14 \pm 0.36$ | $1.490 \pm 0.310$ |  |  |
| 38 | $3666.79 \pm 0.07$ | $2.610 \pm 0.160$ |  |  |
| 39 | $3672.76 \pm 0.15$ | $1.780 \pm 0.190$ |  |  |
| 40 | $3696.99 \pm 0.15$ | $0.420 \pm 0.100$ |  |  |
| 41 | $3710.63 \pm 0.06$ | $2.190 \pm 0.130$ |  |  |
| 42 | $3715.50 \pm 0.06$ | $2.800 \pm 0.150$ |  |  |
| 43 | $3719.15 \pm 0.05$ | $1.420 \pm 0.100$ |  |  |
| 44 | $3725.35 \pm 0.07$ | $1.570 \pm 0.120$ |  |  |
| 45 | $3730.04 \pm 0.02$ | $1.640 \pm 0.070$ |  |  |
| 46 | $3739.77 \pm 0.09$ | $0.940 \pm 0.110$ |  |  |
| 47 | $3757.39 \pm 0.10$ | $1.450 \pm 0.130$ |  |  |
| 48 | $3761.96 \pm 0.09$ | $1.450 \pm 0.160$ | CII $\lambda 1334$ | $z=1.81893$ |
| 49 | $3766.58 \pm 0.28$ | $1.620 \pm 0.280$ |  |  |
| 50 | $3770.17 \pm 0.09$ | $0.670 \pm 0.150$ |  |  |


|  | LgLLZ＇Z＝z 8¢ZIY $\Lambda$ N | 060．0〒0ヶt゙I | 20079\％090¢ | 92 |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 0200才0IE＇I | 900才¢ヶ．9¢0ャ | ¢ 2 |
| 08LLE $Z=z 00 Z$ Y $\times$ IN |  |  |  |  |
|  |  | 020．07061＇t | 200¢92．6t00 | VL |
|  |  | 080．0才0ヶ0＇ |  | \＆ 2 |
|  |  | 0200 0 ¢0980 |  | 22 |
|  |  | $060 \cdot 0 \mp 086^{\circ} \mathrm{I}$ | 90．0¢90．700b | IL |
|  |  | $080^{\circ} 0 \mp 000{ }^{\circ}$ | 50．0〒88．6868 | 02 |
|  |  | 0 D －0¢0198 | 90．0干ャがヤ868 | 69 |
|  |  | $099^{\circ} \mathrm{O} \mp 099{ }^{\text { }}$ | $9^{9} 0 \mp 978268$ | 89 |
|  |  | 0270 00968 | 010才0988968 | 29 |
|  |  |  | $60^{\circ} 0 \mp 90{ }^{\circ}$ 1968 | 99 |
|  | $0 ヶ 8 L Z \cdot Z=z$ 90ZIY III！S | 0¢\％ $0 \mp 002 \cdot 1$ | 7z0 $0 \times 68$ ¢ 968 | 99 |
|  |  | 0010702\％ 0 | 1z0于27：8768 | 59 |
|  |  | 015070¢90 | 770才70 2168 | ¢9 |
|  |  | $01.0 \mp 0890$ |  | 79 |
|  |  | 0600¢0zto | ¢ 0 0† 20 ¢68¢ | 19 |
|  |  | $0 ¢ 10 \mp 08 \varepsilon^{\circ} \mathrm{I}$ | 210才¢\＆6888 | 09 |
|  |  | 01507069 | 200才て16988 | 69 |
| 26ヶ90＇z＝z 09ZIY II！S |  | 0600\％0180 | 80076F＇0988 | 89 |
|  |  | 060 07009 0 |  | LS |
|  | E8FEO ${ }^{\circ}=z$ 097IY IITS | $0180 \mp 020 \%$ |  | 9 c |
|  |  | 0610 0 ¢087 |  | 9 |
|  |  | $081^{\circ} 0 \mp 0900^{\circ}$ | 20＇0干6L＇ 7088 | tc |
|  |  | 011070990 | 0107¢9 8628 | $\varepsilon$ |
|  |  | $081^{\circ} 0 \mp 0 \mathrm{~F}^{\circ} \mathrm{I}$ | $00^{0} 0 \mp 97$ 1628 | z9 |
|  |  | 091．0¥089 $\%$ | $60^{\circ} 078{ }^{\text {¢ }}$ ¢ 9828 | $\underline{19}$ |
| dil Pq！${ }^{\text {ssod }}$ |  | （y）${ }^{\text {r }} \mathrm{M}$ | ${ }^{\text {89\％}} \mathrm{K}$ | ${ }^{\circ} \mathrm{N}$ |

（pənu！quos）：I•G गqR．L
Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathbf{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 77 | $4069.67 \pm 0.15$ | $1.240 \pm 0.230$ |  |  |
| 78 | $4072.22 \pm 0.15$ | $1.840 \pm 0.240$ | NV $\lambda 1242 \quad z=2.27663$ |  |
| 79 | $4078.55 \pm 0.04$ | $2.030 \pm 0.070$ |  | NII $\lambda 1083 \quad z=1.98643$ |
| 80 | $4087.54 \pm 0.12$ | $2.050 \pm 0.170$ |  |  |
| Q 0027+014 |  |  |  |  |
| 1 | $3237.26 \pm 0.14$ | $2.080 \pm 0.380$ |  |  |
| 2 | $3247.19 \pm 0.61$ | $1.980 \pm 1.220$ |  |  |
| 3 | $3249.46 \pm 0.48$ | $1.490 \pm 1.120$ |  |  |
| 4 | $3273.49 \pm 0.15$ | $1.930 \pm 0.360$ |  |  |
| 5 | $3293.73 \pm 0.79$ | $4.230 \pm 2.000$ | Ly $\beta \quad z=2.21113$ |  |
| 6 | $3315.24 \pm 0.15$ | $2.930 \pm 0.350$ |  |  |
| 7 | $3324.99 \pm 0.14$ | $1.880 \pm 0.260$ |  |  |
| 8 | $3329.64 \pm 0.29$ | $2.140 \pm 0.480$ |  |  |
| 9 | $3335.86 \pm 0.39$ | $1.840 \pm 0.540$ |  |  |
| 10 | $3359.20 \pm 0.12$ | $1.380 \pm 0.210$ | Ly $\beta z=2.27496$ |  |
| 11 | $3397.53 \pm 0.09$ | $1.960 \pm 0.220$ |  |  |
| 12 | $3410.82 \pm 0.11$ | $1.460 \pm 0.200$ | NI $\lambda 1200 \quad z=1.84235$ |  |
| 13 | $3415.65 \pm 0.11$ | $1.970 \pm 0.220$ |  |  |
| 14 | $3419.48 \pm 0.13$ | $2.430 \pm 0.290$ |  |  |
| 15 | $3427.85 \pm 0.12$ | $1.750 \pm 0.210$ | SilII $\lambda 1206 z=1.84115$ |  |
| 16 | $3454.36 \pm 0.24$ | $6.190 \pm 1.200$ | Ly $\alpha z=1.84153$ |  |
| 17 | $3498.50 \pm 0.10$ | $2.970 \pm 0.260$ |  |  |
| 18 | $3508.12 \pm 0.13$ | $2.370 \pm 0.270$ | CIV $\lambda 1548 z=1.26593$ |  |
| 19 | $3513.53 \pm 0.08$ | $1.550 \pm 0.170$ | CIV $\lambda 1550 z=1.26566$ |  |
| 20 | $3516.77 \pm 0.17$ | $1.190 \pm 0.210$ |  |  |
| 21 | $3532.58 \pm 0.09$ | $1.040 \pm 0.150$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\bar{W}_{\lambda}(\AA)$ | Identification |
| :---: | :---: | :---: | :---: |
| 22 | $3563.32 \pm 0.57$ | $2.050 \pm 0.990$ |  |
| 23 | $3581.91 \pm 0.12$ | $0.710 \pm 0.150$ | SiII $\lambda 1260 \quad z=1.84183$ |
| 24 | $3590.22 \pm 0.11$ | $0.490 \pm 0.120$ |  |
| 25 | $3594.32 \pm 0.12$ | $0.790 \pm 0.140$ |  |
| 26 | $3602.98 \pm 0.10$ | $1.160 \pm 0.150$ |  |
| 27 | $3607.65 \pm 0.10$ | $1.760 \pm 0.180$ |  |
| 28 | $3622.13 \pm 0.09$ | $1.960 \pm 0.180$ |  |
| 29 | $3629.86 \pm 0.12$ | $1.210 \pm 0.170$ |  |
| 30 | $3638.61 \pm 0.06$ | $1.460 \pm 0.140$ |  |
| 31 | $3696.81 \pm 0.09$ | $2.520 \pm 0.210$ |  |
| 32 | $3722.15 \pm 0.06$ | $1.330 \pm 0.120$ |  |
| 33 | $3749.25 \pm 0.06$ | $1.530 \pm 0.120$ |  |
| 34 | $3753.76 \pm 0.09$ | $1.690 \pm 0.150$ |  |
| 35 | $3762.68 \pm 0.21$ | $1.400 \pm 0.310$ |  |
| 36 | $3765.40 \pm 0.15$ | $1.770 \pm 0.300$ |  |
| 37 | $3768.75 \pm 0.13$ | $1.590 \pm 0.180$ |  |
| 38 | $3783.17 \pm 0.25$ | $0.750 \pm 0.190$ |  |
| 39 | $3785.93 \pm 0.33$ | $0.410 \pm 0.320$ | AlII $\lambda 1670 z=1.98589$ |
| 40 | $3789.09 \pm 0.27$ | $2.030 \pm 0.420$ |  |
| 41 | $3793.53 \pm 0.15$ | $5.280 \pm 0.590$ |  |
| 42 | $3806.84 \pm 0.11$ | $0.980 \pm 0.130$ |  |
| 43 | $3830.07 \pm 0.10$ | $1.140 \pm 0.130$ |  |
| 44 | $3834.96 \pm 0.12$ | $0.410 \pm 0.110$ |  |
| 45 | $3837.17 \pm 0.15$ | $0.640 \pm 0.130$ |  |
| 46 | $3841.00 \pm 0.09$ | $3.290 \pm 0.290$ |  |
| 47 | $3843.85 \pm 0.08$ | $0.750 \pm 0.150$ |  |
| 48 | $3850.46 \pm 0.14$ | $4.220 \pm 0.420$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 49 | $3865.91 \pm 0.10$ | $1.660 \pm 0.160$ |  |  |
| 50 | $3871.28 \pm 0.09$ | $1.570 \pm 0.140$ |  |  |
| 51 | $3890.20 \pm 0.10$ | $2.050 \pm 0.180$ |  |  |
| 52 | $3904.71 \pm 0.11$ | $4.020 \pm 0.330$ |  |  |
| 53 | $3921.89 \pm 0.14$ | $0.440 \pm 0.100$ |  |  |
| 54 | $3931.10 \pm 0.35$ | $0.960 \pm 0.240$ |  |  |
| 55 | $3938.95 \pm 0.07$ | $0.270 \pm 0.060$ |  |  |
| 56 | $3947.96 \pm 0.11$ | $1.890 \pm 0.170$ |  |  |
| 57 | $3959.78 \pm 0.08$ | $2.360 \pm 0.150$ | SilV $\lambda 1393 \quad z=1.84109$ |  |
| 58 | $3966.81 \pm 0.13$ | $2.540 \pm 0.270$ |  |  |
| 59 | $3981.70 \pm 0.07$ | $2.730 \pm 0.160$ |  |  |
| 60 | $3985.98 \pm 0.08$ | $0.700 \pm 0.080$ | SilV $\lambda 1402 \quad z=1.84151$ |  |
| 61 | $3990.72 \pm 0.12$ | $0.280 \pm 0.070$ |  |  |
| 62 | $3993.71 \pm 0.07$ | $0.740 \pm 0.080$ |  |  |
| 63 | $3996.22 \pm 0.04$ | $1.070 \pm 0.070$ |  |  |
| 64 | $4007.46 \pm 0.04$ | $0.930 \pm 0.060$ |  |  |
| 65 | $4026.21 \pm 0.06$ | $0.420 \pm 0.050$ |  |  |
| 66 | $4033.19 \pm 0.06$ | $0.350 \pm 0.040$ |  |  |
| 67 | $4035.51 \pm 0.03$ | $1.120 \pm 0.050$ |  |  |
| 68 | $4037.67 \pm 0.04$ | $0.710 \pm 0.050$ |  |  |
| 69 | $4042.08 \pm 0.05$ | $0.570 \pm 0.040$ |  |  |
|  |  |  | 0 |  |
| 1 | $3568.66 \pm 0.09$ | $0.820 \pm 0.190$ |  |  |
| 2 | $3604.01 \pm 0.06$ | $0.610 \pm 0.140$ |  |  |
| 3 | $3703.98 \pm 0.12$ | $1.020 \pm 0.190$ |  |  |
| 4 | $3762.29 \pm 0.12$ | $0.820 \pm 0.180$ |  |  |


|  |  | 0¢\％0¢0btて | －10才ャで2098 | Iz |
| :---: | :---: | :---: | :---: | :---: |
|  |  | OSTOFOLC＇I | 200788．0098 | 02 |
|  |  | 0910¢022＇0 | 9107 0 ¢ 9698 | 6I |
|  |  | 0910F092＇ı | 80076 $8^{\circ} 169^{\circ}$ | 8I |
|  |  | 09 c －0才06\％＇I | 20．07809998 | 21 |
|  |  | $0 \mathrm{ct} 0 \mp 0 \mathrm{c} 90$ | \＆ $1^{\circ} 0 \mp 61^{\circ} 0 ¢ 98$ | 91 |
|  |  | 00ヶ0¢096．$¢$ | ¢10干じ0ヶ¢8 | ¢1 |
|  |  | $01 Z^{\circ} 0 \mp 00 \mathrm{t}^{\circ} \mathrm{Z}$ |  | bl |
|  |  | 0610戸0iz＇z | 800戸8899898 | \＆I |
|  |  | 091．0¢099．0 |  | 21 |
|  |  | 01z：0〒0tb＇ |  | II |
| 18061＇$z=z 880 \mathrm{I}$ Y IIN |  | $07 \%$ O¢060＇ |  | 01 |
|  |  | $08 \mathrm{~T} 0 \mp 088$ I | 800才79 1 Ltを | 6 |
|  |  | 0680才0¢I＇ | c¢ 0¢0ヶ¢ ¢ ¢ ¢ | 8 |
|  |  | 027＇0¢002．0 | zi $0 \mp$ ¢0＇tzes | 4 |
|  |  | 088 $0 \mp 092^{\prime}$ I | 9\％ $0 \mp 89$ 2LE¢ | 9 |
|  |  | 018．0才089＇ | 070才60zİ\＆ | 9 |
| 9LZz¢ ${ }^{\prime}$ I＝z z0¢IY 10 | $89707 \cdot 7=z \delta^{\prime} \mathcal{S}_{T}$ | 087\％ $0 \mp 062^{\prime} \mathrm{I}$ | ャг 0¢ 20.9888 | － |
|  |  | 099 $0 \mp 006 . z$ | 97．0干ャ9 ¢ 278 | $\varepsilon$ |
|  |  | $089.0 \mp 010{ }^{\circ}$ | $9 \mathrm{9} \cdot 0 \mp \varepsilon \chi^{\circ} \mathrm{Gqz} \mathrm{\%}$ | $\checkmark$ |
|  |  | 0LE＇I $709 \downarrow$ ¢ | て¢0才て！＇8ちて¢ | 1 |


| $200+6 \mathrm{~F} 000$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 09107082．0 | 910才06 7868 | 8 |
|  |  |  |  | 1 |
|  |  | $080007069^{\circ}$ | 70．0FLL＇2088 | 9 |
|  |  | $080^{\circ} 0 \mp 08 \underbrace{\circ}$ | 01．0才02．9828 | $\underline{9}$ |
|  | ио！̣еэу！${ }^{\text {a }}$ | （ $\mathrm{V}^{\text {r }}$ Y $M$ | ${ }^{\text {59\％}} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 22 | $3610.99 \pm 0.16$ | $1.140 \pm 0.170$ |  |  |
| 23 | $3614.51 \pm 0.06$ | $1.440 \pm 0.140$ |  |  |
| 24 | $3617.29 \pm 0.09$ | $1.910 \pm 0.180$ |  |  |
| 25 | $3621.35 \pm 0.22$ | $1.700 \pm 0.530$ |  |  |
| 26 | $3624.00 \pm 0.41$ | $1.650 \pm 0.590$ |  |  |
| 27 | $3643.56 \pm 0.10$ | $0.890 \pm 0.120$ | SiII $\lambda 1526 z=1.38655$ |  |
| 28 | $3667.86 \pm 0.11$ | $3.040 \pm 0.260$ |  |  |
| 29 | $3677.94 \pm 0.12$ | $0.460 \pm 0.110$ |  |  |
| 30 | $3680.04 \pm 0.09$ | $0.930 \pm 0.120$ |  |  |
| 31 | $3695.09 \pm 0.14$ | $0.890 \pm 0.140$ | CIV $\lambda 1548 z=1.38670$ |  |
| 32 | $3698.19 \pm 0.07$ | $1.660 \pm 0.150$ |  |  |
| 33 | $3700.96 \pm 0.13$ | $0.700 \pm 0.130$ | CIV $\lambda 1550 z=1.38652$ |  |
| 34 | $3704.58 \pm 0.12$ | $1.310 \pm 0.150$ |  |  |
| 35 | $3717.51 \pm 0.09$ | $0.990 \pm 0.120$ |  |  |
| 36 | $3720.02 \pm 0.09$ | $0.670 \pm 0.110$ |  | Sill $\lambda 1193 z=2.11744$ |
| 37 | $3733.97 \pm 0.25$ | $0.960 \pm 0.200$ |  |  |
| 38 | $3758.63 \pm 0.05$ | $1.190 \pm 0.100$ |  |  |
| 39 | $3764.84 \pm 0.08$ | $0.880 \pm 0.100$ |  |  |
| 40 | $3780.59 \pm 0.09$ | $2.260 \pm 0.180$ |  |  |
| 41 | $3789.03 \pm 0.06$ | $1.570 \pm 0.100$ | Ly $\alpha z=2.11682$ |  |
| 42 | $3798.18 \pm 0.13$ | $0.810 \pm 0.110$ |  |  |
| 43 | $3806.03 \pm 0.15$ | $0.470 \pm 0.100$ |  |  |
| 44 | $3815.60 \pm 0.09$ | $1.130 \pm 0.110$ |  |  |
| 45 | $3833.99 \pm 0.10$ | $1.610 \pm 0.150$ |  |  |
| 46 | $3838.03 \pm 0.15$ | $0.560 \pm 0.100$ |  |  |
| 47 | $3841.46 \pm 0.15$ | $1.100 \pm 0.220$ |  |  |
| 48 | $3843.91 \pm 0.23$ | $0.890 \pm 0.240$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 49 | $3849.80 \pm 0.09$ | $4.610 \pm 0.360$ | Ly $\alpha z=2.16681$ | $\begin{aligned} & \text { SiII } \lambda 1526 z=1.52163 \\ & \text { SiIII } \lambda 1206 z=2.19088 \end{aligned}$ |
| 50 | $3855.48 \pm 0.06$ | $2.250 \pm 0.120$ |  |  |
| 51 | $3880.09 \pm 0.07$ | $2.620 \pm 0.150$ | $\mathrm{Ly} \alpha z=2.19172$ |  |
| 52 | $3893.78 \pm 0.24$ | $1.610 \pm 0.280$ | Ly $\alpha z=2.20299$ |  |
| 53 | $3899.94 \pm 0.15$ | $0.270 \pm 0.060$ |  |  |
| 54 | $3905.20 \pm 0.13$ | $0.340 \pm 0.060$ |  | CIV $\lambda 1548 z=1.52240$ |
| 55 | $3911.77 \pm 0.10$ | $1.950 \pm 0.150$ |  | CIV $\lambda 1550 z=1.52246$ |
| 56 | $3926.71 \pm 0.10$ | $4.140 \pm 0.310$ |  | Sill $\lambda 1260 z=2.11539$ |
|  |  |  |  | NV $\lambda 1238 z=2.16971$ |
| 57 | $3931.27 \pm 0.06$ | $1.710 \pm 0.090$ |  |  |
| 58 | $3934.85 \pm 0.04$ | $1.200 \pm 0.070$ |  | NV $\lambda 1242 z=2.16610$ |
| 59 | $3937.82 \pm 0.17$ | $0.430 \pm 0.080$ |  |  |
| 60 | $3987.13 \pm 0.16$ | $0.420 \pm 0.060$ | AllI $\lambda 1670 z=1.38638$ |  |
| 61 | $4027.36 \pm 0.14$ | $0.830 \pm 0.090$ |  |  |
| 62 | $4033.56 \pm 0.14$ | $0.540 \pm 0.070$ |  |  |
| 63 | $4057.46 \pm 0.06$ | $0.820 \pm 0.050$ | SiIV $\lambda 1393 z=1.91117$ | $\text { Fell } \lambda 1608 z=1.52258$ $\text { OI } \lambda 1302 z=2.11592$ |
| 64 | $4083.76 \pm 0.12$ | $0.730 \pm 0.080$ | SiIV $\lambda 1402 z=1.91121$ |  |
|  |  |  | Q 0123+257 |  |
| 1 | $3429.76 \pm 0.14$ | $1.750 \pm 0.260$ | $\mathrm{Ly} \beta z=2.34375$ | SilII $\lambda 1206 z=1.84274$ |
| 2 | $3433.08 \pm 0.22$ | $0.790 \pm 0.310$ |  | FeII $\lambda 2600 z=0.32033$ |
| 3 | $3435.16 \pm 0.25$ | $1.140 \pm 0.340$ |  |  |
| 4 | $3455.80 \pm 0.14$ | $2.680 \pm 0.280$ | Ly $\alpha z=1.84271$ | $\mathrm{Ly} \beta$ z 2.36913 |
| 5 | $3473.23 \pm 0.24$ | $1.660 \pm 0.290$ | OVI $\lambda 1031 z=2.36577$ | Fell $\lambda 1143 z=2.03810$ |
| 6 | $3477.76 \pm 0.20$ | $4.540 \pm 0.530$ |  | FeII $\lambda 1145 \quad z=2.03751$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 7 | $3495.82 \pm 0.23$ | $3.260 \pm 0.480$ | OVI $\lambda 1037$ | $z=2.36909$ |
| 8 | $3540.25 \pm 0.04$ | $0.820 \pm 0.120$ |  |  |
| 9 | $3560.66 \pm 0.12$ | $2.120 \pm 0.250$ |  |  |
| 10 | $3584.82 \pm 0.51$ | $2.340 \pm 0.630$ |  |  |
| 11 | $3602.90 \pm 0.24$ | $2.140 \pm 0.330$ |  |  |
| 12 | $3645.20 \pm 0.16$ | $1.740 \pm 0.220$ | NII $\lambda 1083$ | $z=2.36276$ |
| 13 | $3650.09 \pm 0.13$ | $3.310 \pm 0.300$ |  | NI $\lambda 1200 z=2.03767$ |
| 14 | $3670.98 \pm 0.06$ | $0.640 \pm 0.120$ |  |  |
| 15 | $3676.40 \pm 0.23$ | $2.140 \pm 0.320$ |  |  |
| 16 | $3693.13 \pm 0.13$ | $4.320 \pm 0.350$ | MgII $\lambda 2796 \quad z=0.32070$ | Ly $\alpha z=2.03794$ |
| 17 | $3701.91 \pm 0.11$ | $2.510 \pm 0.210$ | MgII $\lambda 2803$ | $z=0.32045$ |
| 18 | $3708.54 \pm 0.12$ | $2.440 \pm 0.220$ |  | OI $\lambda 1302 z=1.84288$ |
| 19 | $3731.60 \pm 0.08$ | $0.670 \pm 0.110$ |  |  |
| 20 | $3735.99 \pm 0.11$ | $1.950 \pm 0.200$ |  |  |
| 21 | $3767.51 \pm 0.09$ | $1.290 \pm 0.130$ | MgI $\lambda 2853$ | $z=0.32056$ |
| 22 | $3775.91 \pm 0.16$ | $0.740 \pm 0.140$ |  |  |
| 23 | $3781.14 \pm 0.15$ | $0.980 \pm 0.150$ |  |  |
| 24 | $3787.46 \pm 0.24$ | $0.690 \pm 0.160$ |  |  |
| 25 | $3795.77 \pm 0.08$ | $0.690 \pm 0.110$ |  |  |
| 26 | $3799.08 \pm 0.08$ | $1.620 \pm 0.140$ |  |  |
| 27 | $3807.59 \pm 0.13$ | $1.900 \pm 0.190$ |  |  |
| 28 | $3845.67 \pm 0.28$ | $2.680 \pm 0.450$ |  |  |
| 29 | $3866.68 \pm 0.10$ | $2.430 \pm 0.180$ |  |  |
| 30 | $3882.63 \pm 0.26$ | $1.270 \pm 0.220$ |  |  |
| 31 | $3889.85 \pm 0.11$ | $1.300 \pm 0.160$ |  |  |
| 32 | $3900.51 \pm 0.09$ | $1.520 \pm 0.130$ |  |  |
| 33 | $3914.51 \pm 0.05$ | $1.000 \pm 0.100$ |  |  |
|  |  |  |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification |
| :---: | :---: | :---: | :---: |
| 34 | $3930.63 \pm 0.15$ | $0.450 \pm 0.090$ |  |
| 35 | $3936.04 \pm 0.21$ | $1.090 \pm 0.160$ |  |
| 36 | $3944.11 \pm 0.08$ | $1.640 \pm 0.130$ |  |
| 37 | $3959.82 \pm 0.09$ | $0.770 \pm 0.110$ |  |
| 38 | $3962.09 \pm 0.16$ | $0.630 \pm 0.120$ |  |
| 39 | $3971.90 \pm 0.13$ | $1.480 \pm 0.330$ |  |
| 40 | $3974.34 \pm 0.18$ | $2.540 \pm 0.360$ |  |
| 41 | $3982.75 \pm 0.07$ | $2.590 \pm 0.140$ |  |
| 42 | $3989.45 \pm 0.16$ | $0.720 \pm 0.100$ |  |
| 43 | $4004.05 \pm 0.04$ | $2.760 \pm 0.090$ |  |
| 44 | $4013.21 \pm 0.05$ | $3.730 \pm 0.120$ |  |
| 45 | $4038.10 \pm 0.08$ | $0.920 \pm 0.070$ |  |
| 46 | $4059.86 \pm 0.03$ | $0.636 \pm 0.035$ |  |
| 47 | $4064.42 \pm 0.07$ | $4.050 \pm 0.230$ | Ly $\alpha z=2.34335$ |


| 47 | $4064.42 \pm 0.07$ | $4.050 \pm 0.230$ | Ly $\alpha z=2.34335$ | SiIII $\lambda 1206 z=2.36876$ |
| :---: | :---: | :---: | :--- | :--- |
|  |  |  | $\mathrm{Q} 0150-202$ |  |
| 1 | $3229.98 \pm 1.04$ | $4.200 \pm 3.150$ |  |  |
| 2 | $3231.74 \pm 0.09$ | $0.390 \pm 0.310$ |  |  |
| 3 | $3234.08 \pm 0.72$ | $2.070 \pm 2.330$ | OVI $\lambda 1031 \quad z=2.13402$ |  |
| 4 | $3249.31 \pm 1.17$ | $2.590 \pm 2.780$ | FeII $\lambda 2382 z=0.36367$ |  |
| 5 | $3252.99 \pm 0.71$ | $3.390 \pm 2.560$ |  | OVI $\lambda 1037 z=2.13506$ |
|  |  |  | FeII $\lambda 2344 z=0.38766$ |  |
| 6 | $3293.81 \pm 0.17$ | $1.860 \pm 0.320$ |  | AlII $\lambda 1854 z=0.77922$ |
| 7 | $3299.95 \pm 0.10$ | $0.920 \pm 0.210$ |  | FeII $\lambda 2382 z=0.38824$ |
| 8 | $3307.86 \pm 0.16$ | $1.820 \pm 0.300$ |  |  |
| 9 | $3358.39 \pm 0.09$ | $2.290 \pm 0.230$ |  |  |
| 10 | $3363.04 \pm 0.11$ | $2.390 \pm 0.250$ | Ly $\alpha z=1.76640$ |  |


|  | $98800 \%=z$ 万K＇T | 091．0干086．0 | 20070¢ 2998 | LE |
| :---: | :---: | :---: | :---: | :---: |
|  | $20900 \%$ \％ OK T | 09z．0干006．1 | ¢107¢ \％¢ ¢98 | 98 |
|  |  | 001．0干0¢9 ${ }^{\circ}$ | $60.0 \mp 96$ ヶャ98 | SE |
|  |  | 08107019 1 | 20．0干II 9898 | VE |
|  | $99010{ }^{\circ} \mathrm{Z}=z$ 90ZIY IIIIS | 0¢t．0干018．1 | 9007¢z 7898 | E¢ |
|  |  |  | 610才1b6798 | 78 |
|  |  | 008．0干089＇1 | 9107LL 0098 | IE |
|  |  | 089．0干069＊0 | 29．0781－1098 | 08 |
|  |  | 065070c9\％ | 8¢07126698 | 67 |
|  |  | 0\＆I＇0干08L＇I | 80．0干じ969¢ | 87 |
| LLL8E $0=z 9897 \mathrm{Y}$ IIP ${ }^{\text {P }}$ | $\varepsilon 8800 \cdot \square=z \mathcal{E 6 I I Y}$ II！S | 02I＇0干078 1 | 81070L6898 | LZ |
|  |  | 0110干0¢F\％ | 110780＇9LCE | 97 |
|  |  | 091．0于0z6：1 | 20．0干960998 | gz |
|  | 97z98：0 $=z 0097$ Y IIP | 07\％＇0干061＇1 |  | $\checkmark Z$ |
|  |  | 0¢t＇0干066．0 | 210干00 28.8 | \＆z |
|  | 187980 $0=z 9897$ Y IIPH | 0210 0 082：0 | 610701 96SE | ZZ |
|  |  | 0 OLO 0 OLL 0 | cz＇0干9 ${ }^{\circ} \mathrm{f6b} \mathrm{\varepsilon}$ | IZ |
|  |  | 065 0 ¢08 ${ }^{\circ} \mathrm{T}$ | 0107E\＆060¢ | 02 |
|  |  | 07\％0才002：0 | 01．070¢ $7 ¢ 5 ¢$ | 6I |
|  |  | 08807079 ${ }^{\circ}$ | 02．0718．6bte | 8I |
|  |  | 0910 0 ¢0980 | 8007059bb\＆ | LI |
|  |  | 0z8．0干097． 7 | 81．0788．${ }^{\circ} \mathrm{tbt}$ | 91 |
|  |  | 0610干098． | 210768：87ヵ¢ | cI |
|  |  | 0LI＇0干090＇ | 01．0706．7\％¢ | bI |
|  |  | 007：0干0\＆5 1 |  | \＆I |
|  |  | $061^{\circ} 0 \mp 08^{\circ} 0$ | 91．0781＇7008 | 21 |
|  | $60 \pm 8 L^{\prime} \%=z$ E80IY IIN | 09z．0¢088． 1 | 万1．07\＆ | 11 |
| ${ }^{\text {d／I }}$ PlqIssod | ио！ұеэy！ | （8）${ }^{\mathrm{Y}} \mathrm{M}$ | ${ }^{59 \%} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 38 | $3659.32 \pm 0.07$ | $1.250 \pm 0.130$ | Ly $\alpha z=2.01012$ |  |
| 39 | $3674.84 \pm 0.06$ | $0.810 \pm 0.090$ |  |  |
| 40 | $3684.81 \pm 0.09$ | $0.900 \pm 0.100$ |  |  |
| 41 | $3690.21 \pm 0.12$ | $0.770 \pm 0.100$ |  | Sill $\lambda 1260 z=1.92775$ |
| 42 | $3693.37 \pm 0.07$ | $1.010 \pm 0.090$ |  | CII $\lambda 13343 z=1.76753$ |
| 43 | $3701.56 \pm 0.21$ | $0.610 \pm 0.120$ |  |  |
| 44 | $3711.03 \pm 0.09$ | $0.770 \pm 0.090$ |  |  |
| 45 | $3715.42 \pm 0.05$ | $3.510 \pm 0.140$ |  |  |
| 46 | $3726.34 \pm 0.66$ | $0.740 \pm 0.290$ |  | NV $\lambda 1238 z=2.00797$ |
| 47 | $3746.73 \pm 0.16$ | $0.300 \pm 0.070$ |  |  |
| 48 | $3766.63 \pm 0.03$ | $1.410 \pm 0.060$ |  |  |
| 49 | $3771.62 \pm 0.04$ | $0.740 \pm 0.050$ |  |  |
| 50 | $3783.56 \pm 0.03$ | $0.960 \pm 0.040$ |  |  |
| 51 | $3788.59 \pm 0.04$ | $0.930 \pm 0.050$ |  | SiII $\lambda 1260 z=2.00581$ |
| 52 | $3792.57 \pm 0.03$ | $1.310 \pm 0.040$ | SiII $\lambda 1260 z=2.00896$ |  |
| 53 | $3810.34 \pm 0.12$ | $6.790 \pm 0.630$ | Ly $\alpha z=2.13435$ | MgII $\lambda 2796 z=0.36261$ |
| 54 | $3820.78 \pm 0.10$ | $0.220 \pm 0.030$ |  | $\begin{aligned} & \text { MgII } \lambda 2803 z=0.36285 \\ & \text { SiII } \lambda 1304 z=1.92921 \end{aligned}$ |
| 55 | $3827.80 \pm 0.14$ | $0.180 \pm 0.030$ |  |  |
| 56 | $3868.16 \pm 0.14$ | $0.580 \pm 0.070$ |  |  |
| 57 | $3883.28 \pm 0.14$ | $2.740 \pm 0.310$ | NV $\lambda 1238 z=2.13465$ | MgII $\lambda 2796$ z $=0.38869$ |
| 58 | $3896.29 \pm 0.16$ | $1.690 \pm 0.210$ | NV $\lambda 1242 z=2.13508$ | MgII $\lambda 2803 z=0.38977$ |
| 59 | $3918.56 \pm 0.17$ | $0.260 \pm 0.060$ | OI $\lambda 1302 z=2.00925$ |  |
| 60 | $4014.49 \pm 0.15$ | $0.420 \pm 0.070$ | CII $\lambda 1334 z=2.00816$ |  |
| Q 0153+744 |  |  |  |  |
| 1 | $3432.34 \pm 0.12$ | $2.840 \pm 0.310$ | Ly $\beta z=2.34626$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 2 | $3439.88 \pm 0.20$ | $1.140 \pm 0.270$ |  |  |
| 3 | $3453.25 \pm 0.11$ | $2.000 \pm 0.250$ | OVI $\lambda 1031 z=2.34641$ |  |
| 4 | $3472.52 \pm 0.23$ | $2.270 \pm 0.370$ | OVI $\lambda 1037$ | $z=2.34663$ |
| 5 | $3501.59 \pm 0.14$ | $2.060 \pm 0.380$ |  |  |
| 6 | $3526.07 \pm 0.14$ | $1.910 \pm 0.290$ |  |  |
| 7 | $3577.96 \pm 0.17$ | $1.280 \pm 0.280$ |  |  |
| 8 | $3601.66 \pm 0.14$ | $1.600 \pm 0.250$ |  |  |
| 9 | $3614.49 \pm 0.13$ | $1.250 \pm 0.220$ |  |  |
| 10 | $3617.92 \pm 0.10$ | $1.290 \pm 0.210$ |  |  |
| 11 | $3624.23 \pm 0.11$ | $0.780 \pm 0.170$ |  |  |
| 12 | $3634.82 \pm 0.11$ | $2.370 \pm 0.250$ |  |  |
| 13 | $3680.75 \pm 0.14$ | $2.320 \pm 0.260$ |  |  |
| 14 | $3712.10 \pm 0.10$ | $2.750 \pm 0.250$ |  |  |
| 15 | $3716.10 \pm 0.11$ | $2.620 \pm 0.250$ |  |  |
| 16 | $3734.63 \pm 0.11$ | $1.860 \pm 0.180$ |  |  |
| 17 | $3753.89 \pm 0.14$ | $0.480 \pm 0.130$ |  |  |
| 18 | $3774.51 \pm 0.07$ | $2.230 \pm 0.150$ |  |  |
| 19 | $3784.84 \pm 0.18$ | $1.140 \pm 0.180$ |  |  |
| 20 | $3797.00 \pm 0.12$ | $0.720 \pm 0.140$ |  |  |
| 21 | $3825.87 \pm 0.29$ | $1.230 \pm 0.240$ |  |  |
| 22 | $3830.64 \pm 0.10$ | $1.280 \pm 0.160$ | FeII $\lambda 1145$ | $z=2.34571$ |
| 23 | $3834.65 \pm 0.10$ | $3.010 \pm 0.210$ |  |  |
| 24 | $3866.69 \pm 0.11$ | $3.880 \pm 0.280$ |  |  |
| 25 | $3874.66 \pm 0.17$ | $2.460 \pm 0.270$ |  |  |
| 26 | $3910.37 \pm 0.10$ | $1.420 \pm 0.130$ |  |  |
| 27 | $3916.95 \pm 0.06$ | $1.680 \pm 0.110$ |  |  |
| 28 | $3933.63 \pm 0.11$ | $1.220 \pm 0.120$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 29 | $3948.15 \pm 0.07$ | $1.390 \pm 0.100$ |  |  |  |
| 30 | $3983.77 \pm 0.07$ | $1.720 \pm 0.100$ |  |  |  |
| 31 | $3998.61 \pm 0.06$ | $1.530 \pm 0.080$ |  |  |  |
| 32 | $4008.91 \pm 0.21$ | $0.740 \pm 0.100$ |  |  |  |
| 33 | $4026.84 \pm 0.15$ | $0.420 \pm 0.060$ |  |  |  |
| 34 | $4037.09 \pm 0.04$ | $0.800 \pm 0.050$ | SiIII $\lambda 1206$ | $z=2.34611$ |  |
| 35 | $4042.77 \pm 0.07$ | $0.360 \pm 0.040$ |  |  |  |
| 36 | $4067.11 \pm 0.02$ | $3.540 \pm 0.050$ | Ly $\alpha z=2.34557$ |  |  |
|  |  |  |  |  |  |
| 1 | $3496.45 \pm 0.32$ | $1.941 \pm 0.473$ |  |  |  |
| 2 | $3524.52 \pm 0.51$ | $2.113 \pm 0.531$ |  |  |  |
| 3 | $3529.93 \pm 0.21$ | $1.780 \pm 0.370$ |  |  |  |
| 4 | $3535.58 \pm 0.25$ | $1.290 \pm 0.580$ |  |  |  |
| 5 | $3537.78 \pm 0.36$ | $1.810 \pm 0.660$ |  | CIV $\lambda 1548 z=1.32813$ |  |
| 6 | $3540.90 \pm 0.10$ | $1.630 \pm 0.280$ |  |  |  |
| 7 | $3604.42 \pm 0.22$ | $1.110 \pm 0.263$ |  |  |  |
| 8 | $3647.38 \pm 0.18$ | $2.150 \pm 0.280$ |  |  |  |
| 9 | $3654.29 \pm 0.17$ | $0.770 \pm 0.170$ |  |  |  |
| 10 | $3665.79 \pm 0.15$ | $0.710 \pm 0.150$ |  |  |  |
| 11 | $3672.48 \pm 0.14$ | $0.550 \pm 0.130$ |  |  |  |
| 12 | $3840.57 \pm 0.06$ | $0.770 \pm 0.110$ |  |  |  |
| 13 | $3908.09 \pm 0.04$ | $1.280 \pm 0.110$ |  |  |  |
| 14 | $3975.41 \pm 0.07$ | $0.740 \pm 0.110$ |  |  |  |
| 15 | $3979.11 \pm 0.09$ | $1.300 \pm 0.140$ |  |  |  |
| 16 | $3992.06 \pm 0.04$ | $0.980 \pm 0.100$ |  |  |  |
| 17 | $4050.22 \pm 0.08$ | $0.440 \pm 0.090$ |  |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | $\mathrm{Q} 0348+061$ |  |
| 1 | $3238.05 \pm 0.20$ | $2.770 \pm 0.530$ |  |  |
| 2 | $3272.71 \pm 0.17$ | $1.600 \pm 0.350$ |  |  |
| 3 | $3331.14 \pm 0.22$ | $2.800 \pm 0.480$ |  |  |
| 4 | $3362.36 \pm 0.25$ | $2.000 \pm 0.570$ |  |  |
| 5 | $3364.35 \pm 0.21$ | $1.260 \pm 0.520$ |  |  |
| 6 | $3373.65 \pm 0.17$ | $1.460 \pm 0.330$ |  |  |
| 7 | $3398.16 \pm 0.35$ | $1.570 \pm 0.880$ |  |  |
| 8 | $3400.40 \pm 0.34$ | $2.780 \pm 0.920$ | Ly $\alpha z=1.79714$ |  |
| 9 | $3453.19 \pm 0.17$ | $2.900 \pm 0.420$ | Ly $\alpha z=1.84056$ |  |
| 10 | $3467.18 \pm 0.12$ | $1.750 \pm 0.270$ |  |  |
| 11 | $3471.79 \pm 0.24$ | $1.750 \pm 0.360$ |  |  |
| 12 | $3476.15 \pm 0.13$ | $1.380 \pm 0.250$ |  |  |
| 13 | $3502.00 \pm 0.28$ | $1.750 \pm 0.390$ |  |  |
| 14 | $3509.57 \pm 0.23$ | $1.550 \pm 0.320$ |  |  |
| 15 | $3555.34 \pm 0.17$ | $1.430 \pm 0.250$ |  |  |
| 16 | $3581.17 \pm 0.13$ | $1.790 \pm 0.220$ | SiIII $\lambda 1206 z=1.96823$ | SiII $\lambda 1260 z=1.84124$ |
| 17 | $3589.96 \pm 0.12$ | $0.660 \pm 0.140$ |  |  |
| 18 | $3607.63 \pm 0.19$ | $6.700 \pm 1.040$ | Ly $\alpha z=1.96760$ |  |
| 19 | $3623.27 \pm 0.12$ | $3.400 \pm 0.330$ |  |  |
| 20 | $3627.89 \pm 0.05$ | $0.840 \pm 0.100$ | NI $\lambda 1200 z=2.02324$ |  |
| 21 | $3648.33 \pm 0.08$ | $1.440 \pm 0.140$ | SiIII $\lambda 1206 z=2.02389$ |  |
| 22 | $3658.78 \pm 0.23$ | $2.590 \pm 0.450$ | SiIII $\lambda 1206 z=2.03255$ |  |
| 23 | $3660.77 \pm 0.07$ | $0.650 \pm 0.270$ |  |  |
| 24 | $3665.41 \pm 0.05$ | $1.770 \pm 0.110$ |  |  |
| 25 | $3675.97 \pm 0.29$ | $9.280 \pm 2.060$ | Ly $\alpha z=2.02382$ | NV $\lambda 1238 z=1.96731$ |
| 26 | $3687.30 \pm 0.09$ | $5.820 \pm 0.440$ | Ly $\alpha z=2.03314$ | NV $\lambda 1242 z=1.96692$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 27 | $3693.45 \pm 0.08$ | $1.300 \pm 0.100$ |  |  |
| 28 | $3811.94 \pm 0.07$ | $0.560 \pm 0.080$ | Sill $\lambda 1260 z=2.02433$ |  |
| 29 | $3969.91 \pm 0.16$ | $0.550 \pm 0.120$ |  |  |
| 30 | $4035.34 \pm 0.11$ | $0.810 \pm 0.120$ | CII $\lambda 1334 z=2.02378$ |  |
| Q 0400+258 |  |  |  |  |
| 1 | $3751.72 \pm 0.75$ | $1.490 \pm 2.060$ |  |  |
| Q 0747+610 |  |  |  |  |
| 1 | $3333.99 \pm 1.16$ | $3.810 \pm 2.650$ |  | NV $\lambda 1242 z=1.68264$ |
| 2 | $3356.88 \pm 0.37$ | $2.130 \pm 0.650$ | $\begin{aligned} & \operatorname{Ly} \beta z=2.27270 \\ & \text { SiIV } \lambda 1393 z=1.41039 \end{aligned}$ | Sill $\lambda 1193 z=1.81313$ |
| 3 | $3359.50 \pm 0.17$ | $1.170 \pm 0.510$ |  |  |
| 4 | $3369.13 \pm 0.10$ | $2.730 \pm 0.240$ | $\mathrm{Ly} \beta \quad z=2.28464$ |  |
| 5 | $3380.75 \pm 0.17$ | $1.120 \pm 0.190$ | SilV $\lambda 1402 z=1.41005$ | Sill $\lambda 1260 z=1.68224$ |
| 6 | $3389.25 \pm 0.21$ | $1.340 \pm 0.230$ | OVI $\lambda 1031 z=2.28439$ | SiII $\lambda 1304 z=1.59838$ <br> NI $\lambda 1135 z=1.98618$ |
| 7 | $3393.22 \pm 0.23$ | $0.770 \pm 0.180$ | SilII $\lambda 1206 z=1.81245$ |  |
| 8 | $3407.82 \pm 0.16$ | $1.320 \pm 0.190$ | OVI $\lambda 1037 z=2.28428$ |  |
| 9 | $3418.84 \pm 0.12$ | $1.120 \pm 0.160$ | Ly $\alpha z=1.81231$ | SiIV $\lambda 1393 z=1.45297$ |
|  |  |  |  | NII $\lambda 1083 z=2.15394$ |
|  |  |  |  | Sill $\lambda 1190 z=1.87197$ |
| 10 | $3422.93 \pm 0.12$ | $1.780 \pm 0.190$ |  |  |
| 11 | $3428.22 \pm 0.10$ | $1.500 \pm 0.160$ | $\mathrm{Ly} \beta z=2.34224$ | Sill $\lambda 1193 z=1.87291$ |
| 12 | $3439.32 \pm 0.08$ | $0.440 \pm 0.180$ |  |  |
| 13 | $3441.00 \pm 0.26$ | $2.650 \pm 0.390$ | $\mathrm{Ly} \beta \quad z=2.35471$ | SiIV $\lambda 1402 z=1.45300$ |
| 14 | $3446.84 \pm 0.12$ | $0.700 \pm 0.130$ | NI $\lambda 1200 z=1.87237$ |  |
| 15 | $3449.45 \pm 0.12$ | $0.520 \pm 0.120$ |  |  |
| 16 | $3457.70 \pm 0.10$ | $0.970 \pm 0.140$ | Ly $\beta z=2.37099$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 17 | $3462.95 \pm 0.09$ | $1.610 \pm 0.170$ | Ly $\beta z=2.37611$ |  |
| 18 | $3466.06 \pm 0.18$ | $1.010 \pm 0.190$ | SiIII $\lambda 1206 z=1.87282$ | CII $\lambda 1334 z=1.59721$ |
| 19 | $3472.26 \pm 0.14$ | $0.510 \pm 0.130$ |  |  |
| 20 | $3479.87 \pm 0.11$ | $1.640 \pm 0.180$ | NII $\lambda 1083 z=2.21024$ |  |
| 21 | $3489.68 \pm 0.08$ | $0.770 \pm 0.180$ |  |  |
| 22 | $3492.36 \pm 0.10$ | $3.220 \pm 0.290$ | Ly $\alpha z=1.87279$ | OI $\lambda 1302 z=1.68196$ |
| 23 | $3497.96 \pm 0.07$ | $1.430 \pm 0.130$ |  | SiII $\lambda 1304 z=1.68172$ |
| 24 | $3507.56 \pm 0.20$ | $0.660 \pm 0.160$ | $\mathrm{Ly} \beta z=2.41960$ |  |
| 25 | $3513.13 \pm 0.10$ | $3.520 \pm 0.270$ |  |  |
| 26 | $3529.48 \pm 0.11$ | $0.690 \pm 0.110$ |  |  |
| 27 | $3544.12 \pm 0.10$ | $2.420 \pm 0.190$ | SiII $\lambda 1260 z=1.81185$ |  |
| 28 | $3554.27 \pm 0.09$ | $1.320 \pm 0.120$ |  | SiII $\lambda 1190 z=1.98573$ |
| 29 | $3558.11 \pm 0.37$ | $0.810 \pm 0.220$ |  | NV $\lambda 1238 z=1.87217$ |
|  |  |  |  | OI $\lambda 1302 z=1.73244$ |
| 30 | $3562.30 \pm 0.36$ | $0.930 \pm 0.240$ | Ly $\beta z=2.47297$ | $\begin{aligned} & \text { NI } \lambda 1135 z=2.13864 \\ & \text { SiII } \lambda 1193 z=1.98527 \end{aligned}$ |
| 31 | $3575.47 \pm 0.20$ | $1.200 \pm 0.180$ |  |  |
| 32 | $3580.03 \pm 0.15$ | $0.320 \pm 0.190$ | Sill $\lambda 1190 z=2.00737$ | CII $\lambda 1334 z=1.68261$ |
| 33 | $3582.37 \pm 0.40$ | $0.970 \pm 0.270$ | NI $\lambda 1200 z=1.98530$ |  |
| 34 | $3588.72 \pm 0.22$ | $0.500 \pm 0.120$ | Sill $\lambda 1193 z=2.00741$ |  |
| 35 | $3600.95 \pm 0.06$ | $0.760 \pm 0.080$ | NI $\lambda 1135 z=2.17270$ |  |
| 36 | $3606.46 \pm 0.12$ | $1.000 \pm 0.120$ |  |  |
| 37 | $3613.73 \pm 0.14$ | $0.550 \pm 0.100$ |  |  |
| 38 | $3618.17 \pm 0.05$ | $2.200 \pm 0.110$ |  | SiIII $\lambda 1206 z=1.99889$ |
| 39 | $3621.03 \pm 0.06$ | $0.690 \pm 0.080$ | Sill $\lambda 1260 z=1.87287$ | SiIV $\lambda 1393 z=1.59804$ |
| 40 | $3629.15 \pm 0.21$ | $2.570 \pm 0.350$ | Ly $\alpha z=1.98530$ | SilII $\lambda 1206 z=2.00800$ |
| 41 | $3635.13 \pm 0.08$ | $1.550 \pm 0.110$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 42 | $3649.25 \pm 0.11$ | $1.550 \pm 0.140$ |  |  |
| 43 | $3655.61 \pm 0.75$ | $3.370 \pm 2.180$ | Ly $\alpha z=2.00707$ | NI $\lambda 1200 \quad z=2.04634$ |
| 44 | $3658.29 \pm 0.64$ | $1.900 \pm 1.930$ | Ly $\alpha z=2.00928$ |  |
| 45 | $3662.58 \pm 1.02$ | $0.880 \pm 0.760$ | OI $\lambda 1302 z=1.81267$ |  |
| 46 | $3664.64 \pm 0.24$ | $0.300 \pm 0.500$ |  |  |
| 47 | $3666.79 \pm 0.16$ | $0.670 \pm 0.170$ |  |  |
| 48 | $3670.29 \pm 0.23$ | $0.860 \pm 0.160$ |  |  |
| 49 | $3677.07 \pm 0.33$ | $1.160 \pm 0.250$ |  | SilII $\lambda 1206 z=2.04772$ |
| 50 | $3686.13 \pm 0.12$ | $0.610 \pm 0.100$ |  |  |
| 51 | $3696.21 \pm 0.13$ | $0.670 \pm 0.100$ |  |  |
| 52 | $3704.91 \pm 0.09$ | $0.960 \pm 0.100$ | Ly $\alpha z=2.04763$ |  |
| 53 | $3720.96 \pm 0.06$ | $0.960 \pm 0.090$ |  |  |
| 54 | $3727.63 \pm 0.14$ | $0.370 \pm 0.090$ |  | NV $\lambda 1238 z=2.00901$ |
| 55 | $3731.54 \pm 0.08$ | $1.770 \pm 0.130$ | CIV $\lambda 1548 z=1.41024$ |  |
| 56 | $3736.14 \pm 0.06$ | $0.310 \pm 0.070$ |  |  |
| 57 | $3738.14 \pm 0.08$ | $1.090 \pm 0.110$ | CIV $\lambda 1550 z=1.41050$ | SiIV $\lambda 1393 z=1.68206$ |
| 58 | $3745.18 \pm 0.05$ | $1.600 \pm 0.090$ | SiII $\lambda 1526 z=1.45311$ |  |
| 59 | $3752.66 \pm 0.16$ | $0.370 \pm 0.090$ | CII $\lambda 1334 z=1.81197$ |  |
| 60 | $3758.15 \pm 0.04$ | $1.380 \pm 0.100$ |  |  |
| 61 | $3761.18 \pm 0.05$ | $2.680 \pm 0.120$ |  | SiIV $\lambda 1402 z=1.68125$ |
| 62 | $3767.37 \pm 0.22$ | $0.490 \pm 0.110$ | NI $\lambda 1200 z=2.13948$ |  |
| 63 | $3771.96 \pm 0.05$ | $2.380 \pm 0.120$ |  |  |
| 64 | $3777.29 \pm 0.07$ | $1.530 \pm 0.100$ |  | Sill $\lambda 1190 z=2.17308$ |
| 65 | $3783.07 \pm 0.34$ | $0.680 \pm 0.190$ | Sill $\lambda 1260 z=2.00143$ |  |
| 66 | $3785.74 \pm 0.07$ | $0.660 \pm 0.120$ |  | Sill $\lambda 1193 z=2.17252$ |
| 67 | $3790.69 \pm 0.11$ | $0.480 \pm 0.090$ | SiII $\lambda 1260 z=2.00747$ |  |
| 68 | $3792.52 \pm 0.12$ | $0.470 \pm 0.100$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\bar{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 69 | $3797.65 \pm 0.04$ | $1.730 \pm 0.090$ | CIV $\lambda 1548 z=1.45294$ |  |
| 70 | $3801.69 \pm 0.11$ | $0.900 \pm 0.370$ |  |  |
| 71 | $3804.10 \pm 0.49$ | $1.200 \pm 0.490$ | CIV $\lambda 1550 z=1.45303$ | SiIII $\lambda 1206 z=2.15300$ |
| 72 | $3807.86 \pm 0.16$ | $1.000 \pm 0.130$ | NI $\lambda 1200 z=2.17321$ | SiIV $\lambda 1393 z=1.73208$ |
| 73 | $3812.02 \pm 0.19$ | $0.990 \pm 0.150$ |  |  |
| 74 | $3816.06 \pm 0.10$ | $1.210 \pm 0.120$ | Ly $\alpha z=2.13906$ |  |
| 75 | $3822.00 \pm 0.60$ | $0.940 \pm 0.390$ |  |  |
| 76 | $3824.89 \pm 0.12$ | $0.740 \pm 0.280$ |  |  |
| 77 | $3827.84 \pm 0.16$ | $0.640 \pm 0.110$ | SiIII $\lambda 1206 z=2.17268$ |  |
| 78 | $3833.37 \pm 0.27$ | $1.120 \pm 0.220$ | CII $\lambda 1334 z=1.87244$ | SilV $\lambda 1402 z=1.73271$ |
| 79 | $3839.64 \pm 0.11$ | $0.690 \pm 0.090$ |  |  |
| 80 | $3843.15 \pm 0.14$ | $0.570 \pm 0.100$ |  |  |
| 81 | $3846.74 \pm 0.04$ | $2.410 \pm 0.100$ |  |  |
| 82 | $3856.56 \pm 0.06$ | $1.170 \pm 0.090$ | Ly $\alpha z=2.17237$ |  |
| 83 | $3863.62 \pm 0.04$ | $1.440 \pm 0.080$ |  |  |
| 84 | $3873.73 \pm 0.09$ | $0.490 \pm 0.080$ | SilII $\lambda 1206 z=2.21072$ |  |
| 85 | $3882.25 \pm 0.08$ | $1.290 \pm 0.110$ |  |  |
| 86 | $3889.15 \pm 0.11$ | $0.320 \pm 0.070$ |  | NV $\lambda 1238 z=2.13940$ |
| 87 | $3896.89 \pm 0.04$ | $1.320 \pm 0.140$ |  |  |
| 88 | $3900.69 \pm 0.12$ | $5.130 \pm 0.450$ |  |  |
| 89 | $3903.29 \pm 0.06$ | $0.850 \pm 0.240$ | Ly $\alpha z=2.21081$ |  |
| 90 | $3906.75 \pm 0.07$ | $3.740 \pm 0.230$ |  |  |
| 91 | $3910.14 \pm 0.13$ | $1.030 \pm 0.120$ |  |  |
| 92 | $3914.96 \pm 0.05$ | $1.120 \pm 0.080$ |  |  |
| 93 | $3922.94 \pm 0.08$ | $1.590 \pm 0.110$ | SiII $\lambda 1304 z=2.00753$ |  |
| 94 | $3927.21 \pm 0.04$ | $1.020 \pm 0.070$ |  |  |
| 95 | $3948.59 \pm 0.22$ | $0.610 \pm 0.120$ |  |  |


|  |  | 060．0才096 ${ }^{\text {I }}$ | 90．0才9s＇LzIt | IZI |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 080．0キ021 ${ }^{\circ}$ |  | 02I |
|  |  | $0 \mathrm{bl} 0 \mp 026 \mathrm{E}$ | 50．0干6¢切じ | 6II |
|  | $\angle Z L \angle E Z=z O S_{T}$ | 090．0干0c9 ${ }^{\text {－}}$ | ع0．0干¢8：860 | 811 |
|  |  | 001＇0干098＇I | 90．0才0¢ 880 b | 211 |
|  |  | 0blomoso | 200干口t＇080 | 9II |
|  | 28¢98\％$=z 0$ ¢ 7 | 0bt＇0才020＇t | 80．0才LF 820 O | ¢ıI |
|  | $6 \mathrm{CLtE} \mathrm{C}^{\prime}=\sim \mathrm{OS} 7$ |  | 0．0〒6下＇¢90 | －II |
|  |  | 0200才069\％ | 90．0干¢0．090\％ | \＆II |
|  |  | 060．0キ096 ${ }^{\text {－}}$ | b00才砍290b | ZII |
|  | c901z\％$z=z$ 097IY II！S | 0800才0¢90 | H＇0才8L＇960t | III |
|  |  | 0110才0990 | 610 0 ¢96 280 t | 0II |
|  | ФtLecz $=z$ ¢6IIY II！S | 0800才0¢50 | 21．0干018z0t | 601 |
|  |  | 0c00才09\％ 0 | 20078 $L^{\circ} 810$ ¢ | 801 |
|  |  | 090 $0 \mp 0 \mathrm{~b}$ \％ 0 | 6007LEC10\％ | 201 |
| 09 LLE \％$=\sim$ 06IIY II！S | $09200 \%=z$ ธ¢¢LY ID | 020 $0 \mp 0 ¢ 90$ | 200干19810t | 901 |
|  |  | 060．0干08 ${ }^{\circ} 0$ |  | ¢01 |
|  |  | 088．0干078．9 | 600干 28.8668 | ¥01 |
|  |  | 020．0干0190 | 200才 28 \％868 | c0I |
| $06 L I Z ' Z=z 88 Z I Y \wedge N$ |  | $060.0 \mp 096.1$ |  | zoI |
|  |  |  | 6007¢9．7268 | 101 |
|  |  | $017.0 \mp 088^{\circ} 0$ | $61^{\circ} 0 \mp 6 \varepsilon^{\circ} \mathrm{L} 268$ | 001 |
|  |  |  | 91．0干LT6968 | 66 |
|  |  |  |  |  |
| 92960 $=\sim$ z 0 ¢TY 10 |  | 0LCOFOLLO | 1z：0788：2968 | 86 |
| 18987＇z＝z 90zIY III！ |  | 060．0才0ヶ6．0 | 90．0キ¢¢＇ヶ968 | 26 |
|  |  | 060．07088．0 | 6007996968 | 96 |
| G．${ }^{\text {Pqussod }}$ | иопреэу！？ | （y）${ }^{\mathrm{r}} \mathrm{M}$ | ${ }^{599} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 122 | $4134.34 \pm 0.06$ | $1.410 \pm 0.080$ |  |  |
| 123 | $4138.23 \pm 0.14$ | $2.020 \pm 0.190$ |  |  |
| 124 | $4150.56 \pm 0.07$ | $0.590 \pm 0.060$ |  |  |
| 125 | $4157.12 \pm 0.02$ | $2.110 \pm 0.060$ | Ly $\alpha=2.41961$ |  |
| 126 | $4161.46 \pm 0.03$ | $1.360 \pm 0.050$ |  |  |
| 127 | $4175.09 \pm 0.11$ | $0.340 \pm 0.060$ |  |  |
| 128 | $4179.84 \pm 0.19$ | $0.440 \pm 0.080$ | OI $\lambda 1302 z=2.20991$ |  |
| 129 | $4182.20 \pm 0.11$ | $0.220 \pm 0.060$ |  |  |
| 130 | $4184.08 \pm 0.04$ | $0.550 \pm 0.040$ |  |  |
| 131 | $4186.00 \pm 0.03$ | $0.690 \pm 0.040$ |  |  |
| 132 | $4189.88 \pm 0.04$ | $0.330 \pm 0.040$ |  |  |
| 133 | $4192.15 \pm 0.08$ | $0.240 \pm 0.050$ | SiIV $\lambda 1393 z=2.00780$ |  |
| 134 | $4193.66 \pm 0.08$ | $0.230 \pm 0.040$ | SiIV $\lambda 1393 z=2.00889$ |  |
| 135 | $4195.41 \pm 0.12$ | $0.190 \pm 0.050$ |  |  |
| 136 | $4198.80 \pm 0.02$ | $1.260 \pm 0.040$ |  |  |
| 137 | $4201.73 \pm 0.10$ | $0.370 \pm 0.050$ |  |  |
| 138 | $4204.39 \pm 0.05$ | $0.300 \pm 0.040$ |  |  |
| 139 | $4220.98 \pm 0.06$ | $0.930 \pm 0.050$ | Ly $\alpha z=2.47214$ | SiIV $\lambda 1402 z=2.00903$ |
| 140 | $4230.33 \pm 0.06$ | $0.390 \pm 0.040$ |  | CIV $\lambda 1548 z=1.73241$ |
| 141 | $4234.98 \pm 0.34$ | $1.770 \pm 0.600$ |  | CII $\lambda 1334 z=2.17338$ |
| 142 | $4237.10 \pm 0.30$ | $1.200 \pm 0.550$ |  | CIV $\lambda 1550 z=1.73277$ |
| 143 | $4241.29 \pm 0.05$ | $0.920 \pm 0.050$ |  |  |
| 144 | $4245.22 \pm 0.11$ | $0.340 \pm 0.050$ |  |  |
| 145 | $4247.20 \pm 0.06$ | $0.370 \pm 0.040$ |  | SiIV $\lambda 1393 z=2.04731$ |
| Q 0836+710 |  |  |  |  |
| 1 | $3243.49 \pm 0.22$ | $1.360 \pm 0.280$ | Ly $\alpha z=1.66807$ | $\operatorname{Ly} \beta z=2.16215$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 2 | $3261.06 \pm 0.15$ | $0.810 \pm 0.220$ | Ly $\beta \quad z=2.17928$ |  |
| 3 | $3263.09 \pm 0.12$ | $1.260 \pm 0.210$ | Ly $\beta \quad z=2.18126$ |  |
| 4 | $3292.38 \pm 0.24$ | $2.600 \pm 0.360$ |  |  |
| 5 | $3308.03 \pm 0.12$ | $0.270 \pm 0.120$ |  |  |
| 6 | $3311.20 \pm 1.47$ | $2.520 \pm 1.000$ |  |  |
| 7 | $3322.54 \pm 0.10$ | $2.170 \pm 0.180$ | Ly $\alpha z=1.73309$ |  |
| 8 | $3350.63 \pm 0.14$ | $1.200 \pm 0.160$ |  |  |
| 9 | $3365.71 \pm 0.13$ | $0.890 \pm 0.140$ |  |  |
| 10 | $3368.34 \pm 0.17$ | $0.540 \pm 0.130$ |  |  |
| 11 | $3380.53 \pm 0.18$ | $1.560 \pm 0.190$ | SiIV $\lambda 1393 \quad z=1.42548$ |  |
| 12 | $3386.19 \pm 0.33$ | $1.480 \pm 0.300$ | NV $\lambda 1238 \quad z=1.73340$ |  |
| 13 | $3396.88 \pm 0.09$ | $0.650 \pm 0.100$ | NV $\lambda 1242 \quad z=1.73324$ |  |
| 14 | $3402.60 \pm 0.21$ | $1.000 \pm 0.160$ | SiIV $\lambda 1402 \quad z=1.42563$ |  |
| 15 | $3415.78 \pm 0.17$ | $1.800 \pm 0.190$ |  |  |
| 16 | $3474.65 \pm 0.10$ | $1.830 \pm 0.160$ |  |  |
| 17 | $3506.67 \pm 0.18$ | $0.440 \pm 0.100$ |  |  |
| 18 | $3509.27 \pm 0.12$ | $0.350 \pm 0.080$ |  |  |
| 19 | $3522.24 \pm 0.05$ | $0.380 \pm 0.060$ |  |  |
| 20 | $3536.92 \pm 0.07$ | $0.890 \pm 0.080$ |  |  |
| 21 | $3545.73 \pm 0.19$ | $1.390 \pm 0.170$ |  |  |
| 22 | $3550.45 \pm 0.15$ | $0.430 \pm 0.080$ | AlIII $\lambda 1854 z=0.91428$ |  |
| 23 | $3558.49 \pm 0.06$ | $0.990 \pm 0.080$ | OI $\lambda 1302 z=1.73274$ |  |
| 24 | $3560.84 \pm 0.08$ | $0.780 \pm 0.080$ | CII $\lambda 1334 z=1.66823$ |  |
| 25 | $3570.59 \pm 0.09$ | $1.310 \pm 0.100$ |  |  |
| 26 | $3585.20 \pm 0.14$ | $0.330 \pm 0.070$ |  |  |
| 27 | $3594.40 \pm 0.12$ | $0.580 \pm 0.080$ |  |  |
| 28 | $3603.73 \pm 0.06$ | $1.150 \pm 0.080$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 29 | $3608.34 \pm 0.05$ | $1.490 \pm 0.090$ | NI $\lambda 1135 z=2.17920$ |  |
| 30 | $3620.37 \pm 0.08$ | $1.250 \pm 0.150$ |  |  |
| 31 | $3622.75 \pm 0.16$ | $1.140 \pm 0.170$ |  |  |
| 32 | $3628.73 \pm 0.03$ | $1.270 \pm 0.060$ |  |  |
| 33 | $3636.80 \pm 0.06$ | $0.800 \pm 0.130$ |  | FeII $\lambda 1145 z=2.17926$ |
| 34 | $3640.06 \pm 0.18$ | $1.590 \pm 0.250$ |  |  |
| 35 | $3644.57 \pm 0.18$ | $0.370 \pm 0.070$ |  |  |
| 36 | $3669.21 \pm 0.06$ | $1.520 \pm 0.070$ |  |  |
| 37 | $3701.94 \pm 0.04$ | $3.060 \pm 0.100$ |  |  |
| 38 | $3718.71 \pm 0.06$ | $0.600 \pm 0.050$ | SiIV $\lambda 1393 z=1.66812$ |  |
| 39 | $3723.77 \pm 0.03$ | $3.670 \pm 0.070$ |  |  |
| 40 | $3727.65 \pm 0.09$ | $0.390 \pm 0.070$ |  |  |
| 41 | $3729.65 \pm 0.06$ | $0.700 \pm 0.070$ |  |  |
| 42 | $3742.47 \pm 0.03$ | $0.880 \pm 0.040$ | SilV $\lambda 1402$ | $z=1.66791$ |
| 43 | $3755.26 \pm 0.05$ | $2.290 \pm 0.090$ | CIV $\lambda 1548$ | $z=1.42556$ |
| 44 | $3761.78 \pm 0.06$ | $1.670 \pm 0.070$ | CIV $\lambda 1550 z=1.42574$ |  |
| 45 | $3771.78 \pm 0.15$ | $0.390 \pm 0.070$ |  |  |
| 46 | $3776.95 \pm 0.11$ | $0.240 \pm 0.040$ |  |  |
| 47 | $3782.21 \pm 0.02$ | $1.590 \pm 0.040$ |  |  |
| 48 | $3790.08 \pm 0.12$ | $0.450 \pm 0.050$ |  |  |
| 49 | $3809.59 \pm 0.16$ | $0.280 \pm 0.050$ |  |  |
| 50 | $3816.49 \pm 0.16$ | $0.180 \pm 0.040$ | NI $\lambda 1200$ | $z=2.18040$ |
| 51 | $3828.26 \pm 0.03$ | $1.040 \pm 0.040$ |  |  |
| 52 | $3831.94 \pm 0.05$ | $0.510 \pm 0.040$ |  |  |
| 53 | $3839.60 \pm 0.04$ | $0.860 \pm 0.050$ |  |  |
| 54 | $3843.55 \pm 0.02$ | $2.370 \pm 0.050$ | Ly $z=2.16167$ |  |
| 55 | $3851.61 \pm 0.27$ | $0.470 \pm 0.080$ |  |  |


|  |  | 090＊0干0¢\％＇0 | もI．0干LC． 9998 | GI |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 0900 －0Zャ 0 | Z107\％c0998 | t |
|  |  | $090.0 \mp 06 L^{\circ}$ | $900 \mp 67.9698$ | \＆I |
|  |  | 020．0干099 0 | 01076c．ce98 | 6I |
| ZLELCI $=$ z Z0ヵIY AIIS |  | 0010才0ヶ2．0 | ¢107¢ 0 0198 | II |
|  |  | $060.0 \mp 0790$ | 11．076L＇0098 | 0I |
|  |  |  | $9 \mathrm{c} 0 \mp 08.66 \mathrm{c}$ | 6 |
|  |  | 081．0于0c0＇I | 91．0干9\％ 289 c | 8 |
|  |  | 0ZI＇0干089＊0 | 910708889¢ | $L$ |
|  |  | 011．0干001＇I | 600干IL 6\＆98 | 9 |
|  |  | 008：0干090\％ | 2I0干9c9zes | c |
|  |  | 00\％＇0干001＇z |  | $\checkmark$ |
|  |  | $0080 \mp 002$ L |  | $\varepsilon$ |
|  |  | 0170 0 02\％ | 900耳 $66 . \mathrm{CIVE}$ | $\boldsymbol{Z}$ |
|  |  | 00LO干0ITC | L\＆0干 266978 | I |
|  | ¢9It 8780 O |  |  |  |
|  |  | 080\％ 0 ¢06\％ 0 | 80．0干E8 8900 | 99 |
|  |  | $0800 \mp 0970$ | 90．0干98．090才 | $\ddagger 9$ |
|  |  | 0800 F0810 | $90.0 \mp 28^{\circ} \mathrm{bz00}$ | $\varepsilon 9$ |
|  |  | $0700 \mp 0170$ | ¢「07¢0＇を\＆6¢ | 79 |
|  |  | 0700 ¢ 0660 | 200干866068 | 19 |
|  |  | 080\％ 0 ¢091．0 | 81．0干00 7068 | 09 |
|  |  | 0700才081＇I | 90\％ 0 ¢ 69.0688 | 69 |
|  |  | 0ヶ0 0 ¢099 ${ }^{\text {－}}$ | 80＇0干60＇L288 | 89 |
|  |  | 0z80耳085 2 | 90＇0708 ${ }^{\circ} 9888$ | 29 |
|  |  | $0 \vdash 0^{\circ} 0 \mp 068^{\circ} 0$ | 20．0才10．8988 | 99 |
| G＇I Plq！ssod | ио！реоу！ | （v）${ }^{\gamma} \mathrm{M}$ | ${ }^{\text {sqo }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |

（рәnu！̣uos）：I•G әqeL
Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 16 | 3667.61 $\pm 0.19$ | $0.570 \pm 0.080$ |  |  |
| 17 | $3836.84 \pm 0.08$ | $0.270 \pm 0.060$ |  |  |
| 18 | $3934.70 \pm 0.13$ | $0.320 \pm 0.070$ |  |  |
| 19 | $3975.93 \pm 0.07$ | $0.490 \pm 0.070$ |  |  |
|  |  |  | Q 0936+368 |  |
| 1 | $3398.67 \pm 0.14$ | $2.320 \pm 0.330$ |  |  |
| 2 | $3403.28 \pm 0.14$ | $3.570 \pm 0.340$ |  |  |
| 3 | $3408.55 \pm 0.14$ | $1.670 \pm 0.240$ |  |  |
| 4 | $3421.29 \pm 0.11$ | $3.404 \pm 0.332$ |  |  |
| 5 | $3431.62 \pm 0.51$ | $2.490 \pm 0.670$ |  |  |
| 6 | $3441.50 \pm 0.10$ | $4.190 \pm 0.310$ |  |  |
| 7 | $3447.80 \pm 0.05$ | $1.340 \pm 0.170$ | CII $\lambda 1334 z=1.58352$ |  |
| 8 | $3455.91 \pm 0.19$ | $1.700 \pm 0.260$ |  |  |
| 9 | $3466.83 \pm 0.20$ | $1.400 \pm 0.250$ |  |  |
| 10 | $3470.95 \pm 0.03$ | $1.200 \pm 0.100$ |  |  |
| 11 | $3476.89 \pm 0.08$ | $0.550 \pm 0.130$ |  |  |
| 12 | $3479.12 \pm 0.10$ | $1.250 \pm 0.220$ |  |  |
| 13 | $3481.61 \pm 0.14$ | $1.360 \pm 0.230$ |  |  |
| 14 | $3496.71 \pm 0.18$ | $0.510 \pm 0.160$ |  |  |
| 15 | $3521.28 \pm 0.11$ | $1.470 \pm 0.170$ |  |  |
| 16 | $3560.26 \pm 0.20$ | $0.790 \pm 0.170$ |  |  |
| 17 | $3574.02 \pm 0.06$ | $1.640 \pm 0.130$ |  |  |
| 18 | $3586.36 \pm 0.07$ | $1.010 \pm 0.120$ |  |  |
| 19 | $3589.10 \pm 0.05$ | $1.740 \pm 0.120$ |  |  |
| 20 | $3624.59 \pm 0.45$ | $0.960 \pm 0.240$ |  |  |
| 21 | $3634.56 \pm 0.03$ | $1.520 \pm 0.060$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 22 | $3646.77 \pm 0.17$ | $0.340 \pm 0.080$ |  |  |
| 23 | $3654.15 \pm 0.04$ | $1.440 \pm 0.070$ |  |  |
| 24 | $3658.67 \pm 0.08$ | $1.520 \pm 0.090$ |  |  |
| 25 | $3662.97 \pm 0.10$ | $0.760 \pm 0.080$ |  |  |
| 26 | $3683.73 \pm 0.03$ | $2.370 \pm 0.070$ |  |  |
| 27 | $3713.91 \pm 0.03$ | $1.330 \pm 0.070$ |  |  |
| 28 | $3727.24 \pm 0.08$ | $0.470 \pm 0.080$ |  |  |
| 29 | $3761.77 \pm 0.04$ | $1.090 \pm 0.070$ |  |  |
| 30 | $3774.94 \pm 0.04$ | $1.240 \pm 0.080$ |  |  |
| 31 | $4000.74 \pm 0.14$ | $1.410 \pm 0.150$ | CIV $\lambda 1548 z=1.58412$ |  |
| 32 | $4006.52 \pm 0.39$ | $1.080 \pm 0.240$ | CIV $\lambda 1550 z=1.58356$ |  |
|  |  |  | Q 0952+335 |  |
| 1 | $3498.23 \pm 0.30$ | $0.951 \pm 0.211$ | FeII $\lambda 1145 z=2.05538$ |  |
| 2 | $3522.75 \pm 0.12$ | $0.716 \pm 0.114$ |  |  |
| 3 | $3527.38 \pm 0.19$ | $0.917 \pm 0.154$ |  |  |
| 4 | $3535.15 \pm 0.09$ | $1.904 \pm 0.146$ | SiIV $\lambda 1393$ | $z=1.53642$ |
| 5 | $3552.36 \pm 0.18$ | $0.503 \pm 0.115$ |  |  |
| 6 | $3558.14 \pm 0.21$ | $1.619 \pm 0.252$ | SilV $\lambda 1402 z=1.53651$ |  |
| 7 | $3561.74 \pm 0.12$ | $1.509 \pm 0.200$ |  |  |
| 8 | $3568.99 \pm 0.08$ | $0.455 \pm 0.079$ | NII $\lambda 1083 z=2.29246$ |  |
| 9 | $3573.93 \pm 0.15$ | $0.575 \pm 0.102$ |  |  |
| 10 | $3578.49 \pm 0.20$ | $0.704 \pm 0.125$ |  |  |
| 11 | $3589.71 \pm 0.06$ | $4.556 \pm 0.206$ |  |  |
| 12 | $3609.17 \pm 0.05$ | $2.261 \pm 0.095$ |  |  |
| 13 | $3620.14 \pm 0.10$ | $0.761 \pm 0.078$ | FeII $\lambda 1143 z=2.16660$ |  |
| 14 | $3625.75 \pm 0.21$ | $0.344 \pm 0.081$ | FeII $\lambda 1145 z=2.16676$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 15 | $3635.89 \pm 0.09$ | $0.961 \pm 0.081$ |  |  |
| 16 | $3639.77 \pm 0.37$ | $0.799 \pm 0.194$ |  |  |
| 17 | $3655.25 \pm 0.12$ | $0.613 \pm 0.094$ |  |  |
| 18 | $3668.00 \pm 0.14$ | $0.914 \pm 0.112$ | FeII $\lambda 2382 z=0.53939$ | SiIII $\lambda 1206 z=2.04020$ |
| 19 | $3672.39 \pm 0.16$ | $0.770 \pm 0.106$ |  |  |
| 20 | $3685.08 \pm 0.11$ | $0.563 \pm 0.089$ |  | Sill $\lambda 1190 z=2.09562$ |
| 21 | $3687.44 \pm 0.07$ | $1.009 \pm 0.138$ | SiIII $\lambda 1206 z=2.05631$ |  |
| 22 | $3690.66 \pm 0.07$ | $3.377 \pm 0.185$ |  |  |
| 23 | $3695.53 \pm 0.11$ | $5.668 \pm 0.366$ | Ly $\alpha z=2.03991$ | Sill $\lambda 1193 z=2.09692$ |
| 24 | $3714.48 \pm 0.06$ | $2.056 \pm 0.096$ | Ly $\alpha z=2.05550$ | NI $\lambda 1200 z=2.09540$ |
| 25 | $3735.26 \pm 0.09$ | $0.824 \pm 0.085$ | SiIII $\lambda 1206 z=2.09594$ |  |
| 26 | $3741.78 \pm 0.33$ | $0.178 \pm 0.210$ |  |  |
| 27 | $3745.65 \pm 0.53$ | $2.132 \pm 0.675$ |  |  |
| 28 | $3764.32 \pm 0.10$ | $30.97 \pm 0.360$ | Ly $\alpha z=2.09649$ | NV $\lambda 1238 z=2.04159$ |
| 29 | $3780.11 \pm 0.38$ | $2.107 \pm 0.377$ |  | NV $\lambda 1242 z=2.04159$ |
| 30 | $3787.32 \pm 0.16$ | $0.954 \pm 0.118$ |  |  |
| 31 | $3795.35 \pm 0.17$ | $0.304 \pm 0.073$ | Fell $\lambda 1143 z=2.31985$ |  |
| 32 | $3800.88 \pm 0.06$ | $1.156 \pm 0.074$ | FeII $\lambda 1145 z=2.31972$ | NI $\lambda 1200 z=2.16740$ <br> Sill $\lambda 1193 z=2.18523$ |
| 33 | $3804.20 \pm 0.07$ | $0.876 \pm 0.074$ |  |  |
| 34 | $3820.49 \pm 0.33$ | $0.424 \pm 0.319$ | SiIII $\lambda 1206 z=2.16658$ | NI $\lambda 1200 z=2.18457$ <br> SiII $\lambda 1190 z=2.21021$ |
| 35 | $3824.22 \pm 0.77$ | $0.814 \pm 0.478$ |  |  |
| 36 | $3829.91 \pm 0.06$ | $1.212 \pm 0.071$ | Sill $\lambda 1193 z=2.20953$ |  |
| 37 | $3833.43 \pm 0.02$ | $0.931 \pm 0.041$ |  |  |
| 38 | $3850.06 \pm 0.04$ | $1.313 \pm 0.062$ | Ly $\alpha z=2.16703$ | SiII $\lambda 1260 z=2.05457$ |
| 39 | $3858.20 \pm 0.13$ | $0.418 \pm 0.068$ |  |  |


|  | $888 \mathrm{I} \varepsilon^{\prime} 7=z 0 \mathrm{~K}_{7}$ |  | 800729 ${ }^{\circ}$ ¢0¢ | 99 |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | ع00才 0 ¢9 880b | b9 |
|  |  | 650079060 | 万0．0干\％¢ 780 b | \＆9 |
|  |  | 9010 0 I8 $9^{\circ} 0$ | 900¢ ${ }^{\circ} 9.910$ b | 79 |
|  | 86081＇z＝z 097IY IITS | 0210 0 160 ${ }^{\circ}$ | \＆1．0干08． 810 b | 19 |
|  |  | $880.0 \mp 09{ }^{\circ} \mathrm{E}$ | 80．0干 $2 \mathrm{t}^{\circ} 700{ }^{\circ}$ | 09 |
|  |  | \＆\％\％ 0 干 28.9 | 50．0干L9．7668 | 69 |
| $01990 \%=z$ D0\＆IY II！S |  | 9900\％ $296^{\circ} 0$ | ¢10 $0 \mp 66^{\circ} 8868$ | 89 |
|  |  | $890.0 \mp ⿰ 688^{\circ} \mathrm{Z}$ | 800712．0868 | L9 |
| $68607 \cdot \zeta=z 88 Z$ IY $\Lambda$ N |  | L20．0干IIGO0 | $61^{\circ} 0 \mp 6 \nabla^{\circ} 9268$ | 99 |
|  | LEz6z\％$=z$ 907IY III！S | LF00\％${ }^{\circ} 9699^{\circ}$ | 700干口z＇zL6E | 9 c |
| ceste $z=z 8611 \mathrm{Y}$ In！ | 820t0\％$=z$ zociY IO | 680．0干0¢\％＇0 | 900干¢96968 | p9 |
|  |  | $990.0 \mp 960$ I |  | $\varepsilon 9$ |
|  |  |  | 8007 98.9768 | 79 |
|  |  | 8800\％ 22.0 | 20．0干09．$¢ 768$ | IS |
|  |  |  | 010干1も1768 | 09 |
|  |  | 29007LIC0 | 80．0干tE6868 | $6{ }^{6}$ |
|  |  | 1010 0 680＊ | 80．0干09．9768 | 80 |
| $27960{ }^{\circ}=z 097$ IY II！S | $970\left[Z \quad Z=z \quad 0 \Omega_{7}\right.$ | 9ZI＇0干¢89＇I | 80．0干19 7068 | Li |
|  |  | 0800 $0^{\circ} 988^{\circ} 0$ | $61^{\circ} 0 \mp 8 L^{\prime} 8688$ | 97 |
|  |  | $9900787 \mathrm{I}^{\circ} \mathrm{T}$ | 10．0干67． 6888 | St |
|  |  | 9900 ¢ 989.0 | 60．0干 26.8888 | Dit |
|  |  |  | 80\％ $0 \mp \square \%$ ¢888 | $\varepsilon$ |
|  |  | 89\％ 0 干 2690 | $99^{\circ} 0 \mp ⿰ 66 \cdot 9 L 8 \varepsilon$ | ZV |
| $\downarrow Z 607 \cdot \boldsymbol{Z}=z$ 90ZIY III！S |  |  |  |  |
|  |  | $901^{\circ} 0 \mp 929.7$ | $900796 \cdot 1288$ | It |
|  |  | － $200 \mp 9280$ |  | $0 \pm$ |
| －${ }^{\text {I I Plqissod }}$ |  | （v）${ }^{\mathrm{r}} \mathrm{M}$ | ${ }^{\text {sqo }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 66 | $4040.94 \pm 0.09$ | $0.263 \pm 0.048$ |  |  |
| 67 | $4046.55 \pm 0.03$ | $2.681 \pm 0.071$ | SilI $\lambda 1260 z=2.21047$ |  |
| 68 | $4055.41 \pm 0.17$ | $0.436 \pm 0.063$ | CII $\lambda 1334 z=2.03802$ |  |
| 69 | $4079.39 \pm 0.04$ | $1.306 \pm 0.050$ | FeIl $\lambda 1608 z=1.53622$ | SiIV $\lambda 1393 z=2.29296$ |
| 70 | $4085.31 \pm 0.08$ | $0.349 \pm 0.043$ |  |  |
| 71 | $4091.67 \pm 0.03$ | $0.998 \pm 0.042$ |  | SiIV $\lambda 1402 z=2.29229$ |
| 72 | $4100.14 \pm 0.04$ | $1.322 \pm 0.053$ |  |  |
| 73 | $4103.67 \pm 0.02$ | $1.431 \pm 0.040$ |  |  |
| 74 | $4108.25 \pm 0.03$ | $1.564 \pm 0.053$ |  |  |
| 75 | $4113.86 \pm 0.17$ | $0.256 \pm 0.048$ |  |  |
| 76 | $4121.47 \pm 0.08$ | $0.604 \pm 0.050$ |  |  |
| 77 | $4126.10 \pm 0.04$ | $0.616 \pm 0.039$ |  |  |
| 78 | $4130.54 \pm 0.02$ | $1.733 \pm 0.039$ | CII $\lambda 1334 z=2.09512$ |  |
| 79 | $4140.17 \pm 0.18$ | $0.324 \pm 0.054$ |  |  |
| 80 | $4147.17 \pm 0.04$ | $1.156 \pm 0.048$ | OI $\lambda 1302 z=2.18481$ |  |
| 81 | $4153.58 \pm 0.05$ | $0.756 \pm 0.041$ |  | SiII $\lambda 1304 z=2.18435$ |
| 82 | $4168.75 \pm 0.24$ | $0.277 \pm 0.057$ |  |  |
| 83 | $4171.81 \pm 0.11$ | $0.142 \pm 0.034$ |  |  |
| 84 | $4174.84 \pm 0.03$ | $1.144 \pm 0.040$ |  |  |
| 85 | $4180.58 \pm 0.08$ | $0.526 \pm 0.046$ | OI $\lambda 1302 z=2.21047$ |  |
| 86 | $4182.84 \pm 0.06$ | $0.286 \pm 0.036$ | Sill $\lambda 1260 z=2.31860$ |  |
| 87 | $4203.49 \pm 0.08$ | $0.131 \pm 0.026$ |  |  |
| 88 | $4206.55 \pm 0.11$ | $0.482 \pm 0.047$ |  |  |
| 89 | $4209.59 \pm 0.03$ | $0.935 \pm 0.037$ |  |  |
| 90 | $4218.70 \pm 0.03$ | $1.705 \pm 0.041$ |  |  |
| 91 | $4223.04 \pm 0.06$ | $0.601 \pm 0.034$ |  |  |
| 92 | $4237.43 \pm 0.03$ | $3.058 \pm 0.058$ | SiIV $\lambda 1393 z=2.04029$ | AlII $\lambda 1670 z=1.53619$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 93 | $4258.33 \pm 0.02$ | $0.687 \pm 0.018$ | SiIV $\lambda 1393 z=2.05529$ |  |
| 94 | $4264.67 \pm 0.02$ | $0.779 \pm 0.020$ | SilV $\lambda 1402$ | $z=2.04017$ |
| 95 | $4267.21 \pm 0.03$ | $0.553 \pm 0.021$ |  |  |
| 96 | $4270.23 \pm 0.05$ | $0.183 \pm 0.018$ |  |  |
| 97 | $4295.41 \pm 0.15$ | $0.367 \pm 0.043$ |  |  |
| 98 | $4304.51 \pm 0.14$ | $0.212 \pm 0.034$ | MgII $\lambda 2796 \quad z=0.53933$ |  |
| 99 | $4314.23 \pm 0.09$ | $0.365 \pm 0.037$ | SiIV $\lambda 1393$ | $z=2.09540$ |
| MgII $\lambda 2803$ | $z=0.53885$ |  |  |  |
| 100 | $4342.16 \pm 0.08$ | $0.140 \pm 0.025$ | SiIV $\lambda 1402 z=2.09542$ |  |
| Q 0955+472 |  |  |  |  |
| 1 | $3489.11 \pm 0.12$ | $1.000 \pm 0.130$ |  |  |
| 2 | $3540.36 \pm 0.12$ | $1.150 \pm 0.120$ |  |  |
| 3 | $3547.33 \pm 0.21$ | $1.170 \pm 0.170$ | Ly $\beta z=2.45837$ | OI $\lambda 1302 z=1.72417$ |
| 4 | $3554.17 \pm 0.09$ | $1.010 \pm 0.090$ | SiII $\lambda 1304 z=1.72481$ |  |
| 5 | $3560.64 \pm 0.07$ | $1.370 \pm 0.090$ | Ly $\beta z=2.47134$ | NII $\lambda 1083 z=2.28475$ |
| 6 | $3567.94 \pm 0.25$ | $1.330 \pm 0.220$ |  |  |
| 7 | $3573.01 \pm 0.13$ | $0.910 \pm 0.090$ |  |  |
| 8 | $3578.61 \pm 0.08$ | $0.830 \pm 0.070$ | Ly $\beta z=2.48887$ |  |
| 9 | $3589.83 \pm 0.05$ | $1.350 \pm 0.070$ |  |  |
| 10 | $3593.50 \pm 0.10$ | $0.740 \pm 0.070$ |  |  |
| 11 | $3606.27 \pm 0.05$ | $2.660 \pm 0.100$ |  |  |
| 12 | $3623.14 \pm 0.17$ | $0.430 \pm 0.070$ |  |  |
| 13 | $3628.02 \pm 0.08$ | $1.060 \pm 0.070$ |  |  |
| 14 | $3633.42 \pm 0.05$ | $2.970 \pm 0.110$ |  |  |
| 15 | $3667.90 \pm 0.16$ | $0.620 \pm 0.080$ |  |  |
| 16 | $3692.89 \pm 0.11$ | $0.440 \pm 0.060$ |  |  |
| 17 | $3714.80 \pm 0.04$ | $0.290 \pm 0.060$ |  |  |


|  |  | 080\％0干092．0 | ¢1．0干19 ${ }^{\circ} \mathrm{F} 68$ | b |
| :---: | :---: | :---: | :---: | :---: |
|  |  | $0 ヶ 00$ ¢091．0 | 0107币L．0z68 | \＆ |
|  |  | $0900 \mp 0220$ | 900796 2168 | 2. |
|  |  | $0200 \mp 008.0$ | 010干ZL．9068 | It |
|  |  | 0c00干0EE0 | 0107 ${ }^{\circ} 6$ 6006 | $0 \pm$ |
|  |  | $0900700 \% 0$ | ［1＇0789＇9688 | 68 |
|  |  | $0900 \mp 0 巾 9.0$ | 90070¢ 2888 | 88 |
|  |  | $0900 \mp 0920$ | c0079L＇z888 | L\＆ |
|  |  | $090 \cdot 0 \mp 0$［ち0 | 810710．8288 | 98 |
|  |  | $090 \cdot 0 \mp 000{ }^{\circ}$ | 8007¢\％${ }^{\circ} \mathrm{L} 88$ | 98 |
| $28800^{\circ} \mathrm{Z}=\mathrm{z}$ GEIIY IN |  | 0900 干0LT 0 | 0107106988 | D¢ |
|  |  | 0L0＇0干0¢E：0 | 910干96．9988 | ¢ $£$ |
|  |  | $080.0 \mp 09 L^{\circ} 0$ | て！0干Z¢＇1988 | Z |
|  |  |  | 11＇0干80＇2988 | I¢ |
|  |  | $090 \cdot 0 \mp 0090$ | $80^{\circ} 0 \mp 78{ }^{\circ} \mathrm{\square} 88 \mathrm{E}$ | 08 |
|  |  | $060.0 \mp 069^{\circ} \mathrm{I}$ | 80070¢9888 | 6 Z |
|  |  | 090．0干098．0 | 200768 ¢ \％8 | 87 |
|  |  | $060 \cdot 0 \mp 079{ }^{\circ}$ | 50071＊088\＆ | $L Z$ |
|  |  | 0800 0 ¢0bI＇I | 8007669788 | 92 |
|  |  | $0010 \mp 06 \square^{\circ} 0$ | L7．0干8L＇718¢ | 92 |
| LUTUE $Z=z$ SEIIY IN |  | 071．0于075＇\％ | 800716．9628 | b\％ |
|  |  | $090.0 \mp 082^{\circ} 0$ | 60．0干26．98L8 | $\varepsilon \tau$ |
|  |  | $060.0 \mp 076.0$ | 010干1Z6LLE | 22 |
|  |  | 060．07068． | 200干LLCGLLE | 12 |
|  |  | 090．0干07\％＇I | 900799．2928 | 02 |
|  |  | $090.0 \mp 080$ I | 900780．98LE | 61 |
|  |  | 0ZI＇0才099＇I | Lİ0F9ILLLE | 81 |
| ${ }^{\text {a }}$ I PqIssod |  | $(\mathrm{y})^{\mathrm{Y}} \mathrm{M}$ | ${ }^{\text {sqo }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{O}$ |



|  |  | 090．0干002＇I | c00\％9c＇zIIT | IL |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 0 O 0 O70ヶ9 0 |  | 02 |
|  |  | $0000 \mp 090 \cdot 1$ | 80．0786 660 b | 69 |
|  |  | $0600 \mp 0070$ | ¢10 0 ¢ $0 ¢ 960$ ¢ | 89 |
|  |  | 0¢00¢7079\％ | म0076\＆ 860 ¢ | 29 |
|  |  | 0200干097＇1 | 80．0干28．680t | 99 |
|  |  | $050.0 \mp 0 \mathrm{O}$－ |  | 99 |
|  |  | 0ャ0．0干09\％ 0 | $60.0 \mp 10620$ b | ¢9 |
|  | $\angle 18 \mathrm{DE} \cdot \mathrm{Z}=z \quad 0 \mathrm{ST}$ | 0LGIF080\％ | 18．0干87\％020 | ¢9 |
|  |  | 891．0円699 $¢$ |  | 79 |
|  |  | 0¢0．0才0IZ\％ | 07：0干EL： 2900 | ［9 |
|  |  | $0 \downarrow 00 \mp 09 \checkmark^{\circ}$ | 100700 $990 \pm$ | 09 |
|  |  | $090.0 \mp 0960$ | c007EL＇IG0t | 69 |
|  |  | $001.0 \mp 068^{\circ} \mathrm{V}$ | 80．0786．2800 | 89 |
|  |  | 0¢0．0干098\％0 | 200791＊IE0ヵ | 49 |
|  |  | 050．0干07\％\％ | LI．0于69．270b | 99 |
|  |  | $0900 \mp 098.0$ | 0z．0干7c\％070t | G9 |
|  | gicter $=z 007 \mathrm{I}$ IN | $070.0 \mp 018.0$ |  | ¢¢ |
|  |  | 0ヶ0．0干00900 | $90.0 \mp 65^{\circ} 010{ }^{\circ}$ | $\varepsilon ¢$ |
|  |  | $050.0 \mp 00 z^{\circ} \mathrm{L}$ |  | Z9 |
|  |  | 0¢0．0干062\％ | 70．0干67． 2668 | IS |
| ¢99b\＆$z=z$ \＆6ItY II！S | $86787^{\prime} 7=z \quad 0 \kappa_{T}$ | $0900 \mp 027^{\circ} \mathrm{T}$ | 70．0干68． 6668 | 0 S |
|  |  | 090070ICO | 200才99＇8868 | $6{ }^{6}$ |
|  |  | 0G00才0ヶて＇ | 80．0干696668 | $8{ }^{5}$ |
|  |  | 0900 0060 I |  | Lb |
|  | $09887{ }^{\circ} \mathrm{Z}=z$ 90ZIY IIIIS | 0900 ¢00\％ 1 | 70．0才92．7968 | $9{ }^{\text {a }}$ |
| 19987． $2=z 007 \mathrm{IY}$ IN |  | $0900 \mp 006^{\circ} \mathrm{I}$ | 20．0702． 2068 | 96 |
| ${ }^{\text {a }}$＇I Plisssod |  | （V）${ }^{\mathrm{r}} \mathrm{M}$ | ${ }^{59}{ }^{\circ} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |


Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 72 | $4122.03 \pm 0.04$ | $1.230 \pm 0.040$ |  |  |
| 73 | $4129.63 \pm 0.16$ | $0.150 \pm 0.040$ |  |  |
| 74 | $4135.93 \pm 0.03$ | $0.950 \pm 0.040$ |  |  |
| 75 | $4143.90 \pm 0.03$ | $2.200 \pm 0.050$ | Ly $\alpha z=2.40866$ | NV $\lambda 1238 z=2.34503$ |
| 76 | $4147.63 \pm 0.09$ | $1.790 \pm 0.140$ |  |  |
| 77 | $4151.36 \pm 0.12$ | $1.060 \pm 0.130$ |  |  |
| 78 | $4156.47 \pm 0.02$ | $1.720 \pm 0.040$ |  |  |
| 79 | $4165.80 \pm 0.05$ | $0.430 \pm 0.030$ |  |  |
| 80 | $4171.10 \pm 0.07$ | $0.340 \pm 0.030$ |  |  |
| 81 | $4203.22 \pm 0.01$ | $1.830 \pm 0.030$ | Ly $\alpha z=2.45753$ |  |
| 82 | $4206.16 \pm 0.02$ | $0.980 \pm 0.030$ | Ly $\alpha z=2.45995$ |  |
| 83 | $4219.02 \pm 0.01$ | $3.370 \pm 0.030$ | Ly $\alpha z=2.47053$ | CIV $\lambda 1548 z=1.72510$ |
| 84 | $4225.19 \pm 0.17$ | $0.132 \pm 0.028$ | CIV $\lambda 1550 z=1.72456$ |  |
| 85 | $4229.81 \pm 0.09$ | $0.140 \pm 0.020$ |  |  |
| 86 | $4240.60 \pm 0.01$ | $2.230 \pm 0.020$ | Ly $\alpha z=2.48828$ |  |
|  |  |  |  |  |
| 1 | $4402.43 \pm 0.12$ | $0.400 \pm 0.050$ |  |  |
| 2 | $4418.41 \pm 0.07$ | $0.670 \pm 0.050$ | CII $\lambda 1334 z=2.31083$ |  |
| 3 | $4425.83 \pm 0.13$ | $0.220 \pm 0.060$ |  |  |
| 4 | $4430.51 \pm 0.83$ | $0.460 \pm 0.190$ |  |  |
| 5 | $4433.32 \pm 0.04$ | $0.750 \pm 0.120$ |  |  |
| 6 | $4452.69 \pm 0.17$ | $0.960 \pm 0.100$ |  |  |
| 7 | $4457.68 \pm 0.04$ | $1.060 \pm 0.050$ |  |  |
| 8 | $4461.26 \pm 0.04$ | $1.510 \pm 0.070$ | NI $\lambda 1200 z=2.71771$ |  |
| 9 | $4464.47 \pm 0.03$ | $1.570 \pm 0.060$ |  |  |
| 10 | $4467.68 \pm 0.12$ | $0.280 \pm 0.050$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 11 | $4471.80 \pm 0.17$ | $0.320 \pm 0.060$ |  |  |
| 12 | $4476.69 \pm 0.10$ | $0.480 \pm 0.060$ |  | NII $\lambda 1083 \quad z=3.13301$ |
| 13 | $4480.15 \pm 0.20$ | $0.410 \pm 0.080$ |  |  |
| 14 | $4483.85 \pm 0.29$ | $0.340 \pm 0.080$ | SiIII $\lambda 1206 \quad z=2.71641$ |  |
| 15 | $4493.46 \pm 0.06$ | $4.370 \pm 0.190$ |  |  |
| 16 | $4497.43 \pm 0.03$ | $2.650 \pm 0.070$ |  |  |
| 17 | $4509.61 \pm 0.19$ | $0.290 \pm 0.190$ |  |  |
| 18 | $4513.30 \pm 0.42$ | $0.950 \pm 0.350$ |  |  |
| 19 | $4518.60 \pm 0.05$ | $3.740 \pm 0.130$ | Ly $\alpha z=2.71696$ |  |
| 20 | $4524.47 \pm 0.14$ | $1.290 \pm 0.130$ |  |  |
| 21 | $4534.00 \pm 0.07$ | $0.450 \pm 0.050$ |  |  |
| 22 | $4536.74 \pm 0.11$ | $0.820 \pm 0.150$ |  |  |
| 23 | $4539.68 \pm 0.39$ | $0.570 \pm 0.160$ |  |  |
| 24 | $4545.28 \pm 0.16$ | $0.360 \pm 0.070$ |  |  |
| 25 | $4554.33 \pm 0.14$ | $1.140 \pm 0.120$ |  |  |
| 26 | $4559.45 \pm 0.04$ | $1.380 \pm 0.050$ |  |  |
| 27 | $4565.88 \pm 0.05$ | $3.120 \pm 0.120$ |  |  |
| 28 | $4571.93 \pm 0.09$ | $0.730 \pm 0.090$ |  |  |
| 29 | $4574.29 \pm 0.13$ | $0.670 \pm 0.100$ |  |  |
| 30 | $4582.90 \pm 0.15$ | $0.390 \pm 0.050$ |  |  |
| 31 | $4592.31 \pm 0.05$ | $1.800 \pm 0.070$ |  |  |
| 32 | $4598.81 \pm 0.23$ | $0.740 \pm 0.110$ | NI $\lambda 1200 z=2.83234$ | NI $\lambda 1135 z=3.05188$ |
| 33 | $4604.10 \pm 0.04$ | $1.940 \pm 0.060$ | NV $\lambda 1238 z=2.71651$ |  |
| 34 | $4613.80 \pm 0.04$ | $1.560 \pm 0.060$ | SiIV $\lambda 1393 z=2.31033$ |  |
| 35 | $4617.85 \pm 0.04$ | $3.780 \pm 0.110$ |  | NV $\lambda 1242 z=2.71567$ |
| 36 | $4629.94 \pm 0.37$ | $0.420 \pm 0.100$ |  |  |
| 37 | $4632.99 \pm 0.20$ | $0.550 \pm 0.150$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 38 | $4636.25 \pm 0.31$ | $0.780 \pm 0.190$ | NII $\lambda 1083 z=3.27702$ | FeII $\lambda 1145 z=3.04934$ |
| 39 | $4642.42 \pm 0.10$ | $1.610 \pm 0.110$ |  | SiIV $\lambda 1402 \quad z=2.30946$ |
| 40 | $4653.30 \pm 0.07$ | $0.920 \pm 0.110$ |  |  |
| 41 | $4655.75 \pm 0.11$ | $1.540 \pm 0.290$ |  |  |
| 42 | $4658.62 \pm 0.15$ | $1.770 \pm 0.820$ | Ly $\alpha$ | $z=2.83214$ |
| 43 | $4661.18 \pm 0.35$ | $3.020 \pm 0.730$ | Ly $\alpha$ | $z=2.83424$ |
| 44 | $4666.66 \pm 0.09$ | $1.570 \pm 0.090$ |  |  |
| 45 | $4670.73 \pm 0.06$ | $1.280 \pm 0.090$ |  |  |
| 46 | $4673.52 \pm 0.09$ | $1.070 \pm 0.090$ |  |  |
| 47 | $4680.93 \pm 0.12$ | $0.740 \pm 0.070$ |  |  |
| 48 | $4689.53 \pm 0.31$ | $0.460 \pm 0.100$ |  |  |
| 49 | $4700.75 \pm 0.03$ | $2.240 \pm 0.050$ |  |  |
| 50 | $4707.37 \pm 0.58$ | $0.220 \pm 0.380$ |  |  |
| 51 | $4710.24 \pm 1.59$ | $0.410 \pm 0.490$ |  |  |
| 52 | $4716.55 \pm 0.07$ | $8.480 \pm 0.450$ |  |  |
| 53 | $4722.44 \pm 0.69$ | $1.800 \pm 0.910$ |  |  |
| 54 | $4726.59 \pm 0.03$ | $3.280 \pm 0.070$ |  |  |
| 55 | $4730.84 \pm 0.08$ | $2.040 \pm 0.120$ |  |  |
| 56 | $4740.89 \pm 0.19$ | $0.580 \pm 0.080$ |  |  |
| 57 | $4749.61 \pm 0.06$ | $0.790 \pm 0.060$ | NV $\lambda 1238$ | $z=3.83397$ |
| 58 | $4753.01 \pm 0.11$ | $0.210 \pm 0.050$ | NI $\lambda 1135 z=3.23866$ |  |
| 59 | $4756.34 \pm 0.14$ | $0.870 \pm 0.100$ |  |  |
| 60 | $4760.03 \pm 0.0$ | $3.520 \pm 0.070$ |  |  |
| 61 | $4765.14 \pm 0.07$ | $0.520 \pm 0.050$ | NV $\lambda 1242$ | $z=3.83418$ |
| 62 | $4771.25 \pm 0.17$ | $0.530 \pm 0.070$ |  |  |
| 63 | $4781.24 \pm 0.04$ | $1.080 \pm 0.060$ |  |  |
| 64 | $4784.14 \pm 0.14$ | $0.610 \pm 0.080$ |  |  |


| $02781 \mathrm{E}=z 00 \mathrm{TIY}$ IN |  | 08L：07010＇I | ¢10干ャて＇696b | 16 |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 011 －$\ddagger 080{ }^{\circ}$ |  | 06 |
|  |  | 020070290 | 01．0干69666p | 68 |
|  |  | 0900才082\％ | 80．0786 \＆ 66 b | 88 |
|  |  | 0900¢0¢TE | 70．0才68976b | 28 |
|  |  | 0900キ0zz\％ | 200円 0 \％ 2766 | 98 |
|  |  | 0200才0980 | $900 \mp 00{ }^{\circ} \mathrm{b}$ ¢ | 98 |
|  |  | 060．0¢070． | It．0才89006b | 8 |
|  |  | 0c00才0610 | เг $0 \mp ¢ 9$ 906ь | $\varepsilon 8$ |
|  |  | 0600¢0980 | 200キE！ 106 亿 | 28 |
|  |  | 060．0才0¢6． | 700才09968b | 18 |
|  |  | 080．0干06E\％ | 07＇0干ャ8．168t | 08 |
|  |  | 090．0干0010 | 1t．0才i0．068 ${ }^{\text {b }}$ | 62 |
|  |  | 0210才009．0 | 7¢0¢¢¢ $288{ }^{\circ}$ | 82 |
|  | 28800 ¢ $¢=z 907 \mathrm{TY}$ III！S | 060．0〒098．0 | 60．0才9¢＇788 | L2 |
|  |  | 020．0干080\％ | 20．0干 $29.928{ }^{\circ}$ | 92 |
| $08 \mathrm{IC} 0{ }^{\circ} \mathrm{E}=z=00 Z \mathrm{IY}$ IN <br> โ $1 L L z \varepsilon=z$ getiv IN |  | 0c00 0 ¢0t＇I | 9007L1＇298b | $\mathrm{c}^{\text {L }}$ |
|  |  | 0g00 0 ¢0670 | 200799＇r98b | 焐 |
|  |  | $0900 \mp 0$ ¢80 | 80．0干 $72.798{ }^{\circ}$ | \＆ 2 |
|  |  | 060．0〒09\％0 | 80．07\＆${ }^{\circ} 6 \mathrm{6} 8{ }^{\circ}$ | Z2 |
|  |  | 020070ヶ0． | 200才85 $788{ }^{\circ}$ | 12 |
|  |  | $0900 \mp 02 \mathrm{~V}^{\circ}$ |  | 02 |
|  |  | $0 \mathrm{CO} 0^{\circ} \mathrm{O} \mp 00 \mathrm{~S}^{\circ} \mathrm{I}$ |  | 69 |
|  |  | $0900 \pm 0 \mathrm{~S} 2 \cdot \mathrm{I}$ | 0．0才00618 | 89 |
|  |  | $0900^{\circ} \mathrm{F} 020^{\circ} \mathrm{I}$ | 90．0〒08018 | 29 |
|  |  | 0¢00¢0690 |  | 99 |
|  |  | $0900 \pm 0 \square^{\circ} \mathrm{O}$ | 20．0784．062\％ | ¢9 |
| $\mathrm{a}^{\prime} \mathrm{I}$ गq！${ }^{\text {Ssod }}$ | ио！ұеэу！？${ }^{\text {appi }}$ | （V）${ }^{\mathrm{r}} \mathrm{M}$ | ${ }^{\text {sq9 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 92 | $4962.53 \pm 0.13$ | $0.370 \pm 0.210$ | SiIII $\lambda 1206 z=3.11316$ |  |
| 93 | $4968.51 \pm 0.16$ | $1.030 \pm 0.110$ |  |  |
| 94 | $4973.31 \pm 0.03$ | $2.250 \pm 0.060$ |  |  |
| 95 | $4979.78 \pm 0.03$ | $5.630 \pm 0.140$ | Ly $\alpha$ | $z=3.09632$ |
| 96 | $4989.67 \pm 0.04$ | $6.410 \pm 0.180$ | Ly $\alpha z=3.10446$ | NI $\lambda 1200 \quad z=3.14981$ |
| 97 | $5001.83 \pm 0.04$ | $7.360 \pm 0.250$ | Ly $\alpha$ | $z=3.11446$ |
| 98 | $5008.56 \pm 0.22$ | $1.280 \pm 0.240$ |  | SiII $\lambda 1302 z=2.83181$ |
| 99 | $5011.88 \pm 0.04$ | $0.920 \pm 0.140$ |  |  |
| 100 | $5014.63 \pm 0.03$ | $1.280 \pm 0.060$ |  | SiIII $\lambda 1206 z=3.83466$ |
| 101 | $5017.39 \pm 0.08$ | $0.560 \pm 0.060$ |  |  |
| 102 | $5020.83 \pm 0.07$ | $1.370 \pm 0.120$ | NV $\lambda 1238$ | $z=3.05291$ |
| 103 | $5023.31 \pm 0.05$ | $2.100 \pm 0.250$ | Ly $\alpha z=3.13213$ |  |
| 104 | $5025.89 \pm 0.11$ | $1.900 \pm 0.190$ |  |  |
| 105 | $5032.29 \pm 0.05$ | $1.760 \pm 0.090$ |  |  |
| 106 | $5035.80 \pm 0.11$ | $0.930 \pm 0.110$ | NV $\lambda 1242$ | $z=3.05196$ |
| 107 | $5041.73 \pm 0.02$ | $1.870 \pm 0.050$ |  | NI $\lambda 1200 z=3.19650$ |
| 108 | $5048.12 \pm 0.04$ | $7.040 \pm 0.230$ |  |  |
| 109 | $5054.04 \pm 0.04$ | $2.670 \pm 0.120$ | Sill $\lambda 1526 z=2.31041$ |  |
| 110 | $5056.83 \pm 0.06$ | $1.570 \pm 0.110$ |  |  |
| 111 | $5064.90 \pm 0.10$ | $0.450 \pm 0.050$ |  |  |
| 112 | $5068.65 \pm 0.08$ | $0.920 \pm 0.070$ | NI $\lambda 1200 z=3.22387$ |  |
| 113 | $5073.31 \pm 0.06$ | $1.030 \pm 0.060$ |  |  |
| 114 | $5078.77 \pm 0.06$ | $7.530 \pm 0.400$ |  |  |
| 115 | $5095.25 \pm 0.09$ | $0.630 \pm 0.050$ | SillI $\lambda 1206 z=3.22316$ | NI $\lambda 1200 z=3.24604$ |
| 116 | $5102.83 \pm 0.03$ | $3.240 \pm 0.080$ | Ly $\alpha z=3.19754$ | SiII $\lambda 1260 z=3.04850$ |
| 117 | $5106.40 \pm 0.05$ | $0.650 \pm 0.050$ |  |  |
| 118 | $5110.84 \pm 0.07$ | $0.350 \pm 0.040$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 119 | $5117.82 \pm 0.08$ | $6.450 \pm 0.390$ | NV $\lambda 1238 z=3.13120$ | CII $\lambda 1334 z=2.83491$ |
| 120 | $5122.31 \pm 0.03$ | $1.100 \pm 0.130$ | SilI $\lambda 1206 z=3.24559$ |  |
| 121 | $5125.54 \pm 0.10$ | $2.170 \pm 0.150$ | CIV $\lambda 1548 z=2.31064$ |  |
| 122 | $5133.60 \pm 0.04$ | $5.830 \pm 0.160$ | Ly $\alpha z=3.22285$ | CIV $\lambda 1550 z=2.31034$ |
|  |  |  |  | NV $\lambda 1242 z=3.13065$ |
|  |  |  |  | NI $\lambda 1200 z=3.27800$ |
| 123 | $5139.35 \pm 0.04$ | $1.300 \pm 0.050$ |  |  |
| 124 | $5144.12 \pm 0.18$ | $0.260 \pm 0.050$ | NV $\lambda 1238 z=3.15243$ |  |
| 125 | $5156.91 \pm 0.08$ | $0.590 \pm 0.050$ |  | SiII $\lambda 1260 z=3.09542$ |
| 126 | $5161.97 \pm 0.03$ | $3.250 \pm 0.070$ | Ly $\alpha z=3.24619$ | SV $\lambda 1242 z=3.15348$ |
|  |  |  |  |  |
|  |  |  |  |  |
| 127 | $5165.41 \pm 0.04$ | $0.780 \pm 0.050$ |  |  |
| 128 | $5172.56 \pm 0.11$ | $1.470 \pm 0.100$ | SiII $\lambda 1260 z=3.10383$ |  |
| 129 | $5195.21 \pm 0.06$ | $3.050 \pm 0.120$ |  |  |
| 130 | $5199.98 \pm 0.05$ | $3.520 \pm 0.130$ | Ly $\alpha z=3.27746$ |  |
| 131 | $5204.38 \pm 0.10$ | $0.610 \pm 0.050$ |  |  |
| 132 | $5207.71 \pm 0.11$ | $0.250 \pm 0.040$ | SiII $\lambda 1260 z=3.13171$ |  |
| 133 | $5214.02 \pm 0.05$ | $1.110 \pm 0.060$ |  |  |
| 134 | $5217.08 \pm 0.03$ | $1.290 \pm 0.050$ |  |  |
| 135 | $5222.57 \pm 0.06$ | $0.580 \pm 0.040$ |  |  |
|  |  |  | Q $1009+299$ |  |
| 1 | $3626.86 \pm 0.04$ | $0.605 \pm 0.034$ |  |  |
| 2 | $3644.95 \pm 0.04$ | $1.084 \pm 0.038$ | Ly $\beta z=2.55354$ |  |
| 3 | $3664.66 \pm 0.14$ | $0.346 \pm 0.058$ | NII $\lambda 1083 z=2.38071$ |  |
| 4 | $3667.22 \pm 0.24$ | $0.211 \pm 0.062$ | OVI $\lambda 1031 z=2.55376$ |  |


| LLもL9 $\%=z$ 980IY IIO | gezeg $=z$ c80IY IN | $6600 \mp ¢ ¢ 97$ | 10．070¢ 6688 | I¢ |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 6700 ¢もIて＇ | 800才7c9888 | $0 \varepsilon$ |
|  |  | 980．0干68900 |  | 67 |
|  |  | $270 \cdot 0 \mp 9290$ | ヤ0．07\％2．0988 | 87 |
|  |  | Lz0．0干b91．0 | ゅ！0干ち68888 | 27 |
|  |  |  | 80．0干01＇1888 | 97 |
|  |  |  | 2007¢18888 | 97 |
|  |  | 8900 ¢G70＇も | 70．0干80＇7288 | ちZ |
|  |  | 670．0干08100 | \＆10790808\＆ | $\varepsilon \overline{1}$ |
|  |  | 8500 ¢ $2866^{\circ} \mathrm{Z}$ | 700721－88LE | Z7 |
|  |  | 98007L991 | ع007E88LLE | L2 |
|  |  | $670.0 \mp 968{ }^{\circ}$ | 800750 $92 L E$ | 07 |
|  |  | 120．0干7\％80 | 97：0干¢z6928 | 6I |
|  |  | $9900 \mp 061.1$ | 5007¢6 992E | 8I |
|  |  | 97007¢ ${ }^{\circ} \mathrm{O}$ | 800799 792E | LI |
|  |  | 6200 $5692^{\circ}$ | L007E\％GgLE | 9I |
|  |  | EG00耳GLEO | 01078966LE | 9I |
|  |  | \＆b00\％ 208.1 | 800790．9bLE | カI |
|  | ${ }^{5} 0919{ }^{\circ} \mathrm{Z}=z \mathrm{C}^{\prime} \mathrm{T}$ | 18007918．0 | 0107¢L68LE | \＆I |
|  |  | L90．0干โIz\％ 0 | 68．0761 ${ }^{\circ} \mathrm{CLLE}$ | ZI |
|  |  |  | 800780 ZILE | II |
|  |  | ঢD0．0干EGG\％ | LI＇0干90．602E | 0I |
|  |  | \＆50．0于Z09\％ | 60．0796 0208 | 6 |
|  |  | LD0．0干702：0 | 900789．1028 | 8 |
|  | $\downarrow 9909 \%=z \mathcal{V}^{\prime} 7$ | 680．0干III＊ | 50．0〒67＊8698 | 2 |
|  | 88399\％$=z$ LEOTY $1 \Lambda 0$ | 870.0 ¢ $187{ }^{\circ}$ | 20078¢9898 | 9 |
|  | $68989^{\prime} Z=z \chi^{\prime} \chi_{T}$ | $880 \cdot 0 \mp 90{ }^{\prime} 1$ | 0107519 $2 \mathrm{L9E}$ | 9 |
| $\mathrm{Cl}^{\text {I Plqussod }}$ |  | $(\mathrm{y})^{\mathrm{Y}} \mathrm{M}$ | ${ }^{\text {sq0 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 32 | $3896.71 \pm 0.04$ | $1.967 \pm 0.088$ |  |  |
| 33 | $3903.47 \pm 0.03$ | $0.516 \pm 0.022$ |  |  |
| 34 | $3909.89 \pm 0.05$ | $0.335 \pm 0.023$ |  |  |
| 35 | $3921.94 \pm 0.03$ | $0.904 \pm 0.027$ |  |  |
| 36 | $3925.63 \pm 0.04$ | $1.232 \pm 0.040$ |  |  |
| 37 | $3934.30 \pm 0.06$ | $0.500 \pm 0.028$ | SilII $\lambda 1206 z=2.26092$ |  |
| 38 | $3937.98 \pm 0.03$ | $0.404 \pm 0.033$ |  |  |
| 39 | $3940.69 \pm 0.07$ | $0.973 \pm 0.056$ |  |  |
| 40 | $3944.40 \pm 0.18$ | $0.153 \pm 0.037$ |  |  |
| 41 | $3955.64 \pm 0.02$ | $6.032 \pm 0.094$ |  |  |
| 42 | $3964.39 \pm 0.01$ | $2.388 \pm 0.031$ | Ly $\alpha z=2.26107$ |  |
| 43 | $3967.84 \pm 0.03$ | $0.714 \pm 0.031$ |  |  |
| 44 | $3969.61 \pm 0.01$ | $0.900 \pm 0.024$ |  |  |
| 45 | $3972.26 \pm 0.02$ | $1.406 \pm 0.030$ |  |  |
| 46 | $3976.00 \pm 0.27$ | $0.342 \pm 0.064$ |  |  |
| 47 | $3981.67 \pm 0.06$ | $0.773 \pm 0.037$ |  |  |
| 48 | $3986.28 \pm 0.02$ | $0.957 \pm 0.025$ |  |  |
| 49 | $3998.40 \pm 0.12$ | $0.214 \pm 0.027$ |  |  |
| 50 | $4006.08 \pm 0.03$ | $0.774 \pm 0.023$ |  |  |
| 51 | $4019.13 \pm 0.03$ | $0.759 \pm 0.024$ |  |  |
| 52 | $4023.56 \pm 0.03$ | $0.675 \pm 0.023$ |  |  |
| 53 | $4029.78 \pm 0.04$ | $0.687 \pm 0.027$ | NI $\lambda 1200 z=2.35815$ |  |
| 54 | $4041.43 \pm 0.01$ | $2.148 \pm 0.028$ |  |  |
| 55 | $4052.22 \pm 0.03$ | $0.563 \pm 0.022$ | SiIII $\lambda 1206 z=2.35865$ |  |
| 56 | $4056.39 \pm 0.06$ | $0.715 \pm 0.036$ | NI $\lambda 1200 z=2.38032$ | SiII $\lambda 1190 z=2.40753$ |
| 57 | $4061.43 \pm 0.11$ | $0.100 \pm 0.031$ |  | FeII $\lambda 1145 z=2.55322$ |
| 58 | $4063.03 \pm 0.12$ | $0.209 \pm 0.038$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 59 | $4074.96 \pm 0.13$ | $0.163 \pm 0.029$ |  |  |
| 60 | $4079.48 \pm 0.05$ | $0.669 \pm 0.036$ | SiIII $\lambda 1206 z=2.38125$ |  |
| 61 | $4082.50 \pm 0.05$ | $1.182 \pm 0.069$ | Ly $\alpha z=2.35823$ |  |
| 62 | $4086.90 \pm 0.02$ | $4.064 \pm 0.085$ | NI $\lambda 1200 \quad z=2.40575$ |  |
| 63 | $4110.06 \pm 0.01$ | $2.047 \pm 0.023$ | Ly $\alpha z=2.38090$ | SilI $\lambda 1260 z=2.26085$ |
|  |  |  |  | SiIII $\lambda 1206 z=2.40659$ |
| 64 | $4127.99 \pm 0.03$ | $1.549 \pm 0.036$ |  | FeII $\lambda 1143 z=2.61613$ |
| 65 | $4134.06 \pm 0.01$ | $1.517 \pm 0.023$ |  |  |
| 66 | $4137.51 \pm 0.02$ | $2.197 \pm 0.037$ |  | FeII $\lambda 1145 z=2.61727$ |
| 67 | $4141.52 \pm 0.01$ | $7.309 \pm 0.042$ | Ly $\alpha z=2.40677$ |  |
| 68 | $4149.87 \pm 0.18$ | $0.143 \pm 0.029$ |  |  |
| 69 | $4154.62 \pm 0.02$ | $0.726 \pm 0.018$ |  |  |
| 70 | $4160.46 \pm 0.03$ | $0.470 \pm 0.021$ |  |  |
| 71 | $4168.72 \pm 0.01$ | $5.140 \pm 0.059$ |  |  |
| 72 | $4174.51 \pm 0.03$ | $0.625 \pm 0.024$ |  |  |
| 73 | $4177.44 \pm 0.11$ | $0.211 \pm 0.027$ |  |  |
| 74 | $4181.40 \pm 0.03$ | $0.905 \pm 0.026$ |  |  |
| 75 | $4196.64 \pm 0.02$ | $0.532 \pm 0.020$ |  |  |
| 76 | $4198.93 \pm 0.02$ | $0.822 \pm 0.024$ |  |  |
| 77 | $4201.46 \pm 0.22$ | $0.137 \pm 0.031$ |  |  |
| 78 | $4205.33 \pm 0.01$ | $1.694 \pm 0.020$ | SiII $\lambda 1193 \quad z=2.52415$ |  |
| 79 | $4211.40 \pm 0.09$ | $0.266 \pm 0.025$ |  |  |
| 80 | $4214.26 \pm 0.11$ | $0.092 \pm 0.019$ |  |  |
| 81 | $4227.42 \pm 0.03$ | $0.631 \pm 0.022$ |  |  |
| 82 | $4232.15 \pm 0.06$ | $0.458 \pm 0.027$ | SiII $\lambda 1260$ | $z=2.35772$ |
| 83 | $4240.03 \pm 0.02$ | $1.279 \pm 0.023$ | SiII $\lambda 1193 z=2.55322$ |  |
| 84 | $4245.80 \pm 0.20$ | $0.298 \pm 0.046$ | OI $\lambda 1302 z=2.26056$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :--- | :---: |
| 85 | $4249.49 \pm 0.13$ | $0.186 \pm 0.036$ |  |  |
| 86 | $4252.39 \pm 0.07$ | $0.459 \pm 0.031$ | SillI $\lambda 1206 z=2.52456$ |  |
| 87 | $4255.67 \pm 0.06$ | $0.234 \pm 0.021$ |  |  |
| 88 | $4259.42 \pm 0.01$ | $2.997 \pm 0.022$ |  |  |
| 89 | $4266.80 \pm 0.01$ | $1.122 \pm 0.016$ |  |  |
| 90 | $4274.72 \pm 0.04$ | $0.419 \pm 0.020$ |  |  |
| 91 | $4279.30 \pm 0.02$ | $0.568 \pm 0.017$ |  |  |
| 92 | $4283.59 \pm 0.01$ | $3.412 \pm 0.028$ | Ly $\alpha z=2.52364$ |  |
| 93 | $4294.07 \pm 0.03$ | $0.567 \pm 0.019$ | SiII $\lambda 1260 z=2.40685$ |  |
| 94 | $4313.70 \pm 0.13$ | $0.560 \pm 0.050$ |  |  |
| 95 | $4316.43 \pm 0.02$ | $1.344 \pm 0.025$ |  |  |
| 96 | $4319.46 \pm 0.01$ | $2.085 \pm 0.024$ | Ly $\alpha=2.55315$ |  |
| 97 | $4325.95 \pm 0.07$ | $0.285 \pm 0.021$ |  |  |
| 98 | $4330.46 \pm 0.03$ | $0.558 \pm 0.024$ |  |  |
| 99 | $4332.71 \pm 0.07$ | $0.237 \pm 0.023$ |  |  |
| 100 | $4336.13 \pm 0.04$ | $0.378 \pm 0.017$ |  |  |
| 101 | $4343.03 \pm 0.01$ | $1.714 \pm 0.018$ |  |  |
| 102 | $4348.71 \pm 0.06$ | $0.731 \pm 0.035$ |  |  |
| 103 | $4352.98 \pm 0.01$ | $1.048 \pm 0.016$ |  |  |
| 104 | $4358.66 \pm 0.02$ | $1.130 \pm 0.019$ | Ly $\alpha z=2.58540$ |  |
| 105 | $4361.61 \pm 0.02$ | $0.477 \pm 0.017$ | SilII $\lambda 1206 z=2.61509$ |  |
| 106 | $4367.82 \pm 0.03$ | $0.425 \pm 0.017$ |  |  |
| 107 | $4372.93 \pm 0.08$ | $0.153 \pm 0.016$ | OI $\lambda 1302$ | $z=2.35819$ |
| 108 | $4376.46 \pm 0.02$ | $0.690 \pm 0.016$ |  |  |
| 109 | $4383.34 \pm 0.01$ | $1.053 \pm 0.014$ | Ly $\alpha z=2.60569$ |  |
| 110 | $4392.78 \pm 0.24$ | $0.151 \pm 0.029$ |  |  |
| 111 | $4395.64 \pm 0.03$ | $0.417 \pm 0.022$ | Ly $\alpha z=2.61581$ |  |


|  |  | $927 \cdot 0 \mp 970 \%$ | 0¢07L9．6bs | 8I |
| :---: | :---: | :---: | :---: | :---: |
|  |  | ILE0干L99\％ | Zv0戸ち8．8zse | 21 |
|  |  | 0ع7．0干8L9 | 2107198zse | 91 |
|  |  | 108．07\＆${ }^{\text {c }}$ ¢ | 0Z07ZI＇9ISE | 91 |
|  |  | çz－0干Z18．8 | ¢1078L¢098 | 1 |
|  |  |  | $69^{\circ} 0 \mp$ ¢ $^{\circ} 8858$ | $\varepsilon I$ |
|  |  | 5970才IE8 | $99^{\circ} 0 \mp 88.02 \mathrm{LE}$ | ZI |
|  |  | 0¢90788¢ ${ }^{\circ}$ | $0 \downarrow 0 \mp \pm 099 \mathrm{EE}$ | II |
|  |  | 90\％ $0 \mp 809^{\circ} \mathrm{E}$ | 070759 LDVE | 01 |
|  |  | 281．0干0ヶ ${ }^{\circ} \mathrm{L}$ |  | 6 |
|  |  |  | 610766 ${ }^{\circ} 98$ ¢ | 8 |
|  |  | 90\％ 0 于0zI $¢$ | 98．0干L¢ $78 \varepsilon 8$ | $L$ |
|  |  | 198．0干076．9 | 010 0 ¢98 8988 | 9 |
|  |  | セ0ヶ0才99\％\％ | Lz＇0干97＇もGz\＆ | 9 |
|  |  | $669.0 \mp 96 \mathrm{~L}$ ¢ |  | $\checkmark$ |
|  |  | $870^{\circ} 0 \mp 219 \%$ |  | $\varepsilon$ |
|  |  | 0LE0干099＇I | LE0耳II「gIz\＆ | 2 |
|  |  | 0¢0．0于0¢9 ${ }^{\text {I }}$ | 10．0甲88．zLz\＆ | I |
|  | $668+20210$ |  |  |  |
|  |  | 610．0干もLE\％ | 70．0干28．07s | 8II |
|  |  | 610．0才0ヶて＇0 | 800才78966䂙 | LII |
|  | 9890\％$\%=z$ zoEIY IO | 810．0干LもT0 |  | 9II |
|  |  | 9700甲6ZI＇0 |  | cII |
|  |  | 7700耳86\％ 0 | 20079086防 | bli |
|  |  |  | 8207¢960㖇 | \＆II |
|  | 90188． $7=z$ Z0¢IY 10 | 910．0干L01．0 |  | ZII |
|  | ио！реәу！риәрI | （8）${ }^{\mathrm{Y}} \mathrm{M}$ | ${ }^{\text {890}} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {abs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 19 | $3568.02 \pm 0.60$ | $3.202 \pm 0.482$ |  |  |
| 20 | $3588.38 \pm 0.45$ | $1.937 \pm 0.316$ |  |  |
| 21 | $3616.92 \pm 0.40$ | $7.475 \pm 0.733$ |  |  |
| 22 | $3634.31 \pm 0.31$ | $0.927 \pm 0.220$ |  |  |
| 23 | $3641.77 \pm 0.23$ | $3.570 \pm 0.302$ |  |  |
| 24 | $3660.98 \pm 0.47$ | $5.821 \pm 0.650$ |  |  |
| 25 | $3673.67 \pm 0.06$ | $1.360 \pm 0.107$ |  |  |
| 26 | $3712.20 \pm 0.22$ | $1.296 \pm 0.240$ |  |  |
| 27 | $3719.27 \pm 0.75$ | $1.486 \pm 0.370$ |  |  |
| 28 | $3729.54 \pm 0.14$ | $2.570 \pm 0.214$ |  |  |
| 29 | $3754.52 \pm 0.14$ | $3.805 \pm 0.852$ | SiIII $\lambda 1206 \quad z=2.11191$ |  |
| 30 | $3765.49 \pm 3.16$ | $2.848 \pm 1.818$ |  |  |
| 31 | $3781.45 \pm 0.09$ | $8.770 \pm 0.277$ | Ly $\alpha=2.11058$ |  |
| 32 | $3792.64 \pm 0.87$ | $3.766 \pm 0.945$ |  |  |
| 33 | $3800.88 \pm 0.11$ | $3.250 \pm 0.545$ |  |  |
| 34 | $3808.18 \pm 0.18$ | $2.852 \pm 0.244$ | Ly $\alpha=2.13258$ |  |
| 35 | $3830.74 \pm 0.29$ | $6.026 \pm 0.735$ |  |  |
| 36 | $3836.82 \pm 0.23$ | $4.962 \pm 0.820$ | Lyo $z=2.15614$ |  |
| 37 | $3847.65 \pm 0.77$ | $3.071 \pm 0.629$ |  |  |
| 38 | $3867.45 \pm 0.21$ | $0.975 \pm 0.186$ |  |  |
| 39 | $3884.48 \pm 0.12$ | $1.086 \pm 0.148$ |  |  |
| 40 | $3907.30 \pm 0.17$ | $7.154 \pm 0.334$ | NV $\lambda 1238$ | $z=2.15404$ |
| 41 | $3921.95 \pm 0.14$ | $1.038 \pm 0.156$ | SiII $\lambda 1260$ | $z=2.11161$ |
| 42 | $3954.77 \pm 0.22$ | $1.308 \pm 0.197$ |  | NV $\lambda 1242$ |
| 43 | $3961.96 \pm 0.23$ | $1.028 \pm 0.187$ |  |  |
| 44 | $3970.18 \pm 0.20$ | $0.802 \pm 0.165$ |  |  |
| 45 | $3977.55 \pm 0.16$ | $2.078 \pm 0.202$ | SiII $\lambda 1260$ | $z=2.15573$ |


|  |  | $060.0 \mp 029^{\prime} 1$ <br>  $0910 \mp 099 \cdot 1$ $0 \varepsilon \mathrm{r}^{\circ} 0 \mp 068^{\circ} 0$ $0210 \mp 06 \mathrm{C} Z$ |  010干062z98 ¢1．0〒89．6098 zz 0〒 II 0798.8298 |  |
| :---: | :---: | :---: | :---: | :---: |
| $9 L I+01 Z \mathrm{I} 0$ |  |  |  |  |
|  |  | 29\％00．099 | 97．0708918 ${ }^{\text {b }}$ | 99 |
|  |  |  |  | ゅ9 |
|  | ZLILİZ＝z Z0tIY AIS | 6910¢9¢¢＇土 | LI0才b0 ¢98b | ¢9 |
|  | Z9LIT＇Z $=z$ E6EIY NI！S | I¢T0キ9¢6 ${ }^{\text {L }}$ | แ10才ャ898¢ | 79 |
|  |  |  | 280¢02 2876 | 19 |
|  |  | 01t＇0キてI8＇0 |  | 09 |
|  |  | z010才192．I | 200才02 80zt | 69 |
|  |  | b¢10¢9798 | 010768 78 Lb | 89 |
|  |  | \＆1t0¢1980 | －t $0 \mp$ ¢0092Lt | L9 |
|  |  | 6110キ729\％ | 200¢ 26.19 「t | 99 |
|  |  | $8910 \mp 806.9$ | $80.0 \mp 00 \mathrm{zcIb}$ | g 9 |
|  |  | Lgiomege i | 710キ7698しち | ts |
|  |  | L910 0 ¢ 22.1 | 210¢¢8＇teit | $\varepsilon 9$ |
|  |  | 81ヵ0干も988 | 980¢Zヶて\％ | zs |
|  |  | ๖IE0才918． |  | 19 |
|  |  | 20z 0¢0¢c＇b | u0才Is980b | 09 |
|  |  | 8LIOFE6L0 | LZ0干69\％LOD | 6 b |
|  |  | LIZ．0才Z09＇ | $97^{\circ} \mathbf{0}$ ¢80890t | $8{ }^{8}$ |
|  |  |  | $080 \mp 76$ 切 | Lb |
|  |  | ャ0\％ $0 \mp 9788^{\circ}$ | $68^{\circ} 0799 \mathrm{gcot}$ | $9{ }^{\text {9 }}$ |
| $\mathrm{Cl}^{\text {I }}$ Pq！ |  | （X）${ }^{\text {r }} \mathrm{M}$ | ${ }^{\text {890 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |

（рәпи！̣иоэ）： $\mathrm{I} \cdot \mathrm{g}$ ә $\mathrm{TqP}_{\mathrm{L}}$



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 33 | $3842.65 \pm 0.06$ | $1.090 \pm 0.070$ |  |  |
| 34 | $3847.26 \pm 0.04$ | $2.780 \pm 0.110$ |  |  |
| 35 | $3850.45 \pm 0.04$ | $2.050 \pm 0.100$ | SiII $\lambda 1260 \quad z=2.05488$ |  |
| 36 | $3858.64 \pm 0.04$ | $2.230 \pm 0.100$ | CII $\lambda 1334$ | $z=1.89137$ |
| 37 | $3862.18 \pm 0.05$ | $2.900 \pm 0.120$ |  | SiIII $\lambda 1206 z=2.19820$ |
| 38 | $3868.21 \pm 0.07$ | $0.660 \pm 0.070$ |  |  |
| 39 | $3873.63 \pm 0.07$ | $0.520 \pm 0.060$ |  | NV $\lambda 1238 z=2.12249$ |
| 40 | $3880.81 \pm 0.12$ | $0.320 \pm 0.060$ |  | NV $\lambda 1242 z=2.12262$ |
| 41 | $3887.02 \pm 0.04$ | $5.050 \pm 0.130$ | Ly $\alpha z=2.19742$ |  |
| 42 | $3905.18 \pm 0.22$ | $0.570 \pm 0.120$ |  |  |
| 43 | $3912.48 \pm 0.07$ | $1.240 \pm 0.080$ |  |  |
| 44 | $3921.93 \pm 0.07$ | $1.010 \pm 0.070$ |  |  |
| 45 | $3938.23 \pm 0.03$ | $1.790 \pm 0.060$ | SiII $\lambda 1260 \quad z=2.12453$ |  |
| 46 | $3951.72 \pm 0.03$ | $3.320 \pm 0.080$ |  |  |
| 47 | $3962.60 \pm 0.13$ | $0.270 \pm 0.060$ |  |  |
| 48 | $3968.08 \pm 0.03$ | $2.080 \pm 0.060$ |  |  |
| 49 | $3972.60 \pm 0.12$ | $0.370 \pm 0.060$ |  |  |
| 50 | $3980.64 \pm 0.06$ | $2.320 \pm 0.210$ |  |  |
| 51 | $3985.24 \pm 0.07$ | $5.600 \pm 0.320$ |  |  |
| 52 | $3988.94 \pm 0.08$ | $0.430 \pm 0.120$ |  |  |
| 53 | $4008.67 \pm 0.06$ | $0.530 \pm 0.050$ |  |  |
| 54 | $4019.82 \pm 0.10$ | $0.360 \pm 0.060$ |  |  |
| 55 | $4025.53 \pm 0.03$ | $1.710 \pm 0.060$ |  |  |
| 56 | $4030.28 \pm 0.08$ | $1.250 \pm 0.080$ | SiIV $\lambda 1393 z=1.89167$ | SiII $\lambda 1260 z=2.19756$ |
| 57 | $4036.64 \pm 0.07$ | $0.240 \pm 0.040$ |  |  |
| 58 | $4051.89 \pm 0.04$ | $1.060 \pm 0.060$ |  |  |
| 59 | $4056.09 \pm 0.13$ | $1.070 \pm 0.090$ | SiIV $\lambda 1402 z=1.89149$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 60 | $4076.21 \pm 0.09$ | $0.390 \pm 0.050$ | CII $\lambda 1334 z=2.05441$ |  |
| 61 | $4079.24 \pm 0.05$ | $0.800 \pm 0.060$ |  |  |
| 62 | $4086.72 \pm 0.02$ | $2.270 \pm 0.060$ |  |  |
| 63 | $4098.64 \pm 0.36$ | $0.400 \pm 0.090$ |  |  |
| 64 | $4102.71 \pm 0.08$ | $0.550 \pm 0.060$ |  |  |
| 65 | $4106.86 \pm 0.03$ | $0.960 \pm 0.100$ |  |  |
| 66 | $4110.13 \pm 0.08$ | $3.020 \pm 0.160$ |  |  |
| 67 | $4122.80 \pm 0.04$ | $0.410 \pm 0.050$ |  |  |
| 68 | $4147.81 \pm 0.28$ | $0.560 \pm 0.090$ |  |  |
| 69 | $4154.51 \pm 0.04$ | $1.290 \pm 0.060$ |  |  |
| 70 | $4160.72 \pm 0.08$ | $0.450 \pm 0.050$ |  |  |
| 71 | $4163.77 \pm 0.04$ | $0.890 \pm 0.050$ | OI $\lambda 1302 z=2.19756$ |  |
| 72 | $4168.79 \pm 0.05$ | $2.100 \pm 0.080$ | CII $\lambda 1334$ | $z=2.12378$ |
| 73 | $4182.67 \pm 0.09$ | $0.150 \pm 0.030$ |  |  |
| 74 | $4186.91 \pm 0.02$ | $3.010 \pm 0.050$ |  |  |
| 75 | $4193.58 \pm 0.11$ | $0.550 \pm 0.060$ |  |  |
| 76 | $4203.36 \pm 0.03$ | $1.890 \pm 0.050$ |  |  |
| 77 | $4209.02 \pm 0.02$ | $2.340 \pm 0.050$ |  |  |
| 78 | $4212.46 \pm 0.03$ | $1.560 \pm 0.050$ |  |  |
| 79 | $4220.58 \pm 0.05$ | $0.800 \pm 0.060$ |  |  |
| 80 | $4222.76 \pm 0.03$ | $1.020 \pm 0.050$ |  |  |
| 81 | $4228.90 \pm 0.05$ | $1.210 \pm 0.050$ |  |  |
| 82 | $4234.32 \pm 0.16$ | $0.800 \pm 0.080$ |  |  |
| 83 | $4241.21 \pm 0.14$ | $0.260 \pm 0.040$ |  |  |
| 84 | $4256.38 \pm 0.07$ | $0.330 \pm 0.040$ |  |  |
| 85 | $4259.99 \pm 0.03$ | $0.920 \pm 0.030$ |  |  |
| 86 | $4266.24 \pm 0.11$ | $0.540 \pm 0.050$ | CII $\lambda 1334 z=2.19680$ |  |


| GIL9I＇I＝z 8\％GIY AID |  | $0 ¢ 70 \mp 069^{\circ} \mathrm{E}$ | 80．0761－g¢EE | ZI |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 0bI 0 0 098．0 |  | II |
|  |  | 0110干09\％ 0 | い「0干じも¢ | 01 |
|  |  | 0¢T0¢0¢9＊0 | 810干0L0 0 ¢ | 6 |
|  |  | 0910才0¢L＇0 | 210干67＇10¢E | 8 |
|  |  | 0bて＇0才0LE＇I | 0z＇0干98 L6zE | 1 |
|  |  | 0¢T．0才0990 |  | 9 |
|  |  | 028．0干098 ${ }^{\text {I }}$ |  | 9 |
| L6GL8＇I＝z GEITY IN |  | 0¢10才0890 | \＆107LI＇も9Z\＆ | $\checkmark$ |
|  |  | 0¢7＇0干00ヶ ${ }^{\circ}$ | LI＇0干8L＇09\％\＆ | $\varepsilon$ |
|  |  | 0L2．0干0ちて＇\＆ | 98．0728．70z8 | $\zeta$ |
|  |  | 081070190 | 010756．00z8 | 1 |
| ャ6Z＋182I O |  |  |  |  |
|  |  | 0G00干0ちて＇I |  | 66 |
|  |  |  | 6007¢ ${ }^{\circ} \mathrm{CBE}$ | 86 |
|  |  | 0900 $0088^{\circ} 0$ | 980干6L＇tLEt | 26 |
|  |  | 0900干0Lて＇V | 200788．098t | 96 |
|  | SEZLS $=z$ oKT | $0 \mathrm{0} 0{ }^{\circ} 0 \mp 099{ }^{\circ} \mathrm{C}$ | 200708 $2 \mathrm{8Eも}$ | 96 |
|  |  | 080．0干090＇I | 10．0干口 $9.288 \%$ | 『6 |
|  |  | 06007062．0 | 90079I「98Et | 86 |
|  |  | 010．0干089\％0 | 20．0769 288 b | 76 |
|  |  | 060 0 ¢088 0 |  | 16 |
|  |  | 08007088． 7 | 10．0干12．908t | 06 |
|  |  | 050＇0干098\％ | 80．0干66．262b | 68 |
|  |  | 0b00¢098．0 | $80.0 \mp 90888 \mathrm{~b}$ | 88 |
|  |  | 0ヶ007091 1 | 10．0干6L． $2 \angle Z \%$ | 28 |
| CII Plq！${ }^{\text {ssod }}$ |  | （V）${ }^{\mathrm{Y}} \mathrm{M}$ | ${ }^{\text {sq0 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{O}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 13 | $3360.93 \pm 0.05$ | $2.910 \pm 0.150$ |  | CIV $\lambda 1550 z=1.16725$ |
| 14 | $3372.16 \pm 0.10$ | $0.780 \pm 0.130$ |  |  |
| 15 | $3383.58 \pm 0.12$ | $0.860 \pm 0.130$ |  |  |
| 16 | $3387.35 \pm 0.13$ | $1.190 \pm 0.150$ |  |  |
| 17 | $3391.57 \pm 0.17$ | $0.530 \pm 0.137$ |  |  |
| 18 | $3402.70 \pm 0.15$ | $0.530 \pm 0.110$ |  |  |
| 19 | $3426.85 \pm 0.16$ | $0.840 \pm 0.130$ |  |  |
| 20 | $3433.19 \pm 0.15$ | $0.490 \pm 0.110$ |  |  |
| 21 | $3443.03 \pm 0.04$ | $2.000 \pm 0.100$ |  |  |
| 22 | $3449.79 \pm 0.13$ | $1.780 \pm 0.180$ |  |  |
| 23 | $3453.77 \pm 0.08$ | $1.610 \pm 0.130$ | SiIV $\lambda 1393 z=1.47803$ |  |
| 24 | $3476.69 \pm 0.12$ | $0.760 \pm 0.110$ | SiIV $\lambda 1402 z=1.47844$ |  |
| 25 | $3495.64 \pm 0.07$ | $0.960 \pm 0.100$ | Ly $\alpha z=1.87548$ |  |
| 26 | $3511.47 \pm 0.07$ | $1.280 \pm 0.110$ |  |  |
| 27 | $3530.18 \pm 0.19$ | $0.540 \pm 0.110$ |  |  |
| 28 | $3534.42 \pm 0.16$ | $1.160 \pm 0.140$ |  |  |
| 29 | $3538.58 \pm 0.05$ | $1.440 \pm 0.080$ |  |  |
| 30 | $3554.35 \pm 0.08$ | $0.370 \pm 0.070$ |  |  |
| 31 | $3568.22 \pm 0.07$ | $0.330 \pm 0.060$ |  |  |
| 32 | $3570.55 \pm 0.11$ | $0.440 \pm 0.070$ |  |  |
| 33 | $3579.07 \pm 0.20$ | $0.600 \pm 0.120$ |  |  |
| 34 | $3582.21 \pm 0.06$ | $1.400 \pm 0.130$ |  |  |
| 35 | $3585.50 \pm 0.22$ | $0.800 \pm 0.160$ |  |  |
| 36 | $3588.96 \pm 0.04$ | $1.490 \pm 0.090$ |  |  |
| 37 | $3598.06 \pm 0.05$ | $0.400 \pm 0.050$ |  |  |
| 38 | $3613.12 \pm 0.08$ | $0.430 \pm 0.060$ |  |  |
| 39 | $3616.37 \pm 0.03$ | $1.590 \pm 0.060$ |  |  |
|  |  |  |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {abs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 40 | $3621.25 \pm 0.06$ | $1.180 \pm 0.070$ |  | AlII $\lambda 1670 z=1.16739$ |
| 41 | $3647.20 \pm 0.25$ | $0.610 \pm 0.110$ |  |  |
| 42 | $3650.22 \pm 0.89$ | $0.360 \pm 0.900$ |  |  |
| 43 | $3653.88 \pm 1.38$ | $0.920 \pm 1.210$ |  |  |
| 44 | $3658.65 \pm 0.05$ | $0.690 \pm 0.050$ |  |  |
| 45 | $3674.31 \pm 0.0$ | $3.130 \pm 0.050$ |  |  |
| 46 | $3738.19 \pm 0.14$ | $0.370 \pm 0.060$ | CIV $\lambda 1548 \quad z=1.41453$ |  |
| 47 | $3745.09 \pm 0.02$ | $1.150 \pm 0.040$ | CIV $\lambda 1550 z=1.41498$ | OI $\lambda 1302 z=1.87604$ |
| 48 | $3793.63 \pm 0.10$ | $0.680 \pm 0.070$ |  |  |
| 49 | $3806.82 \pm 0.03$ | $1.240 \pm 0.050$ |  |  |
| 50 | $3836.51 \pm 0.05$ | $0.960 \pm 0.070$ | CIV $\lambda 1548$ | $z=1.47804$ |
| 51 | $3842.66 \pm 0.07$ | $0.570 \pm 0.060$ | CIV $\lambda 1550 z=1.47789$ |  |
|  |  |  | Q $1323-107$ |  |
| 1 | $3204.56 \pm 0.05$ | $0.460 \pm 0.160$ |  |  |
| 2 | $3206.34 \pm 0.20$ | $1.590 \pm 0.300$ |  |  |
| 3 | $3216.42 \pm 0.16$ | $0.820 \pm 0.190$ |  |  |
| 4 | $3220.10 \pm 0.10$ | $3.040 \pm 0.240$ | OI $\lambda 1302 z=1.47288$ |  |
| 5 | $3224.99 \pm 0.11$ | $0.290 \pm 0.090$ |  |  |
| 6 | $3234.71 \pm 0.05$ | $1.510 \pm 0.210$ | CII $\lambda 1334 z=1.42385$ |  |
| 7 | $3240.85 \pm 0.32$ | $2.710 \pm 0.490$ |  |  |
| 8 | $3245.61 \pm 0.29$ | $2.030 \pm 0.340$ | OI $\lambda 1302 z=1.49247$ |  |
| 9 | $3250.47 \pm 0.07$ | $0.680 \pm 0.110$ |  | SiII $\lambda 1304 z=1.84145$ |
| 10 | $3260.76 \pm 0.08$ | $0.540 \pm 0.110$ |  |  |
| 11 | $3270.96 \pm 0.19$ | $0.780 \pm 0.170$ |  |  |
| 12 | $3272.90 \pm 0.05$ | $0.690 \pm 0.110$ |  |  |
| 13 | $3281.28 \pm 0.13$ | $0.720 \pm 0.130$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 14 | $3299.99 \pm 0.09$ | $2.410 \pm 0.170$ | CII $\lambda 1334 z=1.47277$ |  |
| 15 | $3307.67 \pm 0.12$ | $0.720 \pm 0.130$ |  |  |
| 16 | $3309.47 \pm 0.10$ | $0.320 \pm 0.130$ |  |  |
| 17 | $3312.28 \pm 0.45$ | $1.030 \pm 0.340$ |  |  |
| 18 | $3329.50 \pm 0.49$ | $1.100 \pm 0.300$ |  |  |
| 19 | $3339.06 \pm 0.24$ | $0.850 \pm 0.160$ | Ly $\beta z=2.25533$ |  |
| 20 | $3352.69 \pm 0.15$ | $0.420 \pm 0.090$ |  |  |
| 21 | $3357.41 \pm 0.17$ | $1.780 \pm 0.210$ | $\mathrm{Ly} \beta z=2.27321$ |  |
| 22 | $3362.25 \pm 0.06$ | $2.180 \pm 0.130$ |  |  |
| 23 | $3370.80 \pm 0.06$ | $1.880 \pm 0.110$ |  |  |
| 24 | $3374.56 \pm 0.09$ | $1.020 \pm 0.100$ |  |  |
| 25 | $3379.06 \pm 0.09$ | $0.548 \pm 0.089$ | Ly $\beta z=2.29432$ | SiIV $\lambda 1393 z=1.42443$ |
| 26 | $3384.32 \pm 0.16$ | $0.483 \pm 0.117$ |  |  |
| 27 | $3388.24 \pm 0.06$ | $0.750 \pm 0.140$ |  |  |
| 28 | $3393.42 \pm 0.12$ | $1.730 \pm 0.140$ | $\mathrm{Ly} \beta z=2.30832$ |  |
| 29 | $3400.72 \pm 0.11$ | $0.310 \pm 0.170$ |  | SiIV $\lambda 1402 z=1.42429$ |
| 30 | $3403.07 \pm 0.39$ | $1.100 \pm 0.320$ |  |  |
| 31 | $3406.39 \pm 0.11$ | $0.560 \pm 0.190$ |  |  |
| 32 | $3409.35 \pm 0.44$ | $0.650 \pm 0.240$ | $\mathrm{Ly} \beta z=2.32385$ | NI $\lambda 1200 z=1.84113$ |
| 33 | $3419.57 \pm 0.07$ | $1.360 \pm 0.100$ |  |  |
| 34 | $3422.50 \pm 0.08$ | $0.740 \pm 0.090$ |  |  |
| 35 | $3436.74 \pm 0.08$ | $1.730 \pm 0.110$ |  |  |
| 36 | $3447.05 \pm 0.12$ | $1.370 \pm 0.110$ |  |  |
| 37 | $3454.39 \pm 0.06$ | $0.910 \pm 0.070$ | Ly $\alpha z=1.84155$ |  |
| 38 | $3461.20 \pm 0.05$ | $2.280 \pm 0.090$ |  |  |
| 39 | $3489.30 \pm 0.15$ | $0.140 \pm 0.050$ |  |  |
| 40 | $3491.71 \pm 0.51$ | $1.350 \pm 0.310$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 41 | $3510.01 \pm 0.23$ | $0.340 \pm 0.090$ |  |  |
| 42 | $3513.57 \pm 0.09$ | $1.570 \pm 0.110$ |  |  |
| 43 | $3517.05 \pm 0.12$ | $0.290 \pm 0.070$ |  |  |
| 44 | $3519.81 \pm 0.10$ | $1.220 \pm 0.100$ |  |  |
| 45 | $3526.01 \pm 0.43$ | $0.790 \pm 0.200$ |  |  |
| 46 | $3529.76 \pm 0.18$ | $1.060 \pm 0.120$ |  |  |
| 47 | $3544.74 \pm 0.17$ | $0.820 \pm 0.110$ |  |  |
| 48 | $3550.80 \pm 0.14$ | $0.950 \pm 0.190$ |  |  |
| 49 | $3552.88 \pm 0.14$ | $1.180 \pm 0.200$ |  |  |
| 50 | $3557.81 \pm 0.17$ | $1.110 \pm 0.130$ |  |  |
| 51 | $3579.07 \pm 0.09$ | $0.360 \pm 0.060$ |  |  |
| 52 | $3582.43 \pm 0.06$ | $1.210 \pm 0.080$ |  |  |
| 53 | $3586.71 \pm 0.05$ | $1.000 \pm 0.060$ |  |  |
| 54 | $3613.01 \pm 0.03$ | $2.000 \pm 0.060$ |  |  |
| 55 | $3629.72 \pm 0.04$ | $1.910 \pm 0.080$ |  |  |
| 56 | $3643.56 \pm 0.40$ | $0.570 \pm 0.140$ |  |  |
| 57 | $3648.00 \pm 0.05$ | $1.340 \pm 0.080$ |  |  |
| 58 | $3652.01 \pm 0.05$ | $1.680 \pm 0.080$ |  |  |
| 59 | $3659.17 \pm 0.04$ | $0.270 \pm 0.040$ |  |  |
| 60 | $3693.85 \pm 0.11$ | $0.320 \pm 0.070$ |  |  |
| 61 | $3696.50 \pm 0.09$ | $0.590 \pm 0.070$ |  |  |
| 62 | $3701.24 \pm 0.15$ | $0.480 \pm 0.080$ | Sill $\lambda 1526$ | $z=1.42433$ |
| 63 | $3703.92 \pm 0.13$ | $0.170 \pm 0.100$ |  |  |
| 64 | $3706.28 \pm 0.33$ | $0.660 \pm 0.180$ |  |  |
| 65 | $3714.16 \pm 0.03$ | $3.390 \pm 0.090$ |  |  |
| 66 | $3726.25 \pm 0.30$ | $0.700 \pm 0.160$ |  |  |
| 67 | $3728.57 \pm 0.08$ | $0.270 \pm 0.100$ |  |  |
|  |  |  |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 68 | $3736.95 \pm 0.04$ | $1.650 \pm 0.070$ |  |  |
| 69 | $3739.58 \pm 0.04$ | $1.430 \pm 0.070$ |  |  |
| 70 | $3751.83 \pm 0.03$ | $0.770 \pm 0.050$ |  |  |
| 71 | $3757.45 \pm 0.03$ | $1.530 \pm 0.050$ |  |  |
| 72 | $3763.81 \pm 0.06$ | $0.810 \pm 0.050$ |  |  |
| 73 | $3768.90 \pm 0.03$ | $1.440 \pm 0.050$ |  |  |
| 74 | $3772.99 \pm 0.07$ | $0.530 \pm 0.050$ |  |  |
| 75 | $3778.29 \pm 0.22$ | $0.260 \pm 0.060$ |  |  |
| 76 | $3791.98 \pm 0.12$ | $0.210 \pm 0.050$ | CII $\lambda 1334 z=1.84143$ |  |
| 77 | $3796.17 \pm 0.24$ | $0.250 \pm 0.060$ |  |  |
| 78 | $3801.03 \pm 0.07$ | $0.200 \pm 0.060$ |  |  |
| 79 | $3803.44 \pm 0.47$ | $0.630 \pm 0.150$ |  |  |
| 80 | $3812.65 \pm 0.04$ | $1.490 \pm 0.060$ |  |  |
| 81 | $3816.92 \pm 0.01$ | $1.060 \pm 0.040$ |  |  |
| 82 | $3820.91 \pm 0.05$ | $1.110 \pm 0.050$ |  |  |
| 83 | $3825.39 \pm 0.03$ | $1.290 \pm 0.050$ |  |  |
| 84 | $3828.17 \pm 0.04$ | $1.130 \pm 0.060$ | CIV $\lambda 1548$ | $z=1.47266$ |
| 85 | $3831.78 \pm 0.05$ | $0.720 \pm 0.050$ |  |  |
| 86 | $3834.68 \pm 0.06$ | $0.820 \pm 0.060$ | CIV $\lambda 1550$ | $z=1.47275$ |
| 87 | $3842.39 \pm 0.05$ | $1.650 \pm 0.070$ |  |  |
| 88 | $3846.24 \pm 0.07$ | $0.620 \pm 0.050$ |  |  |
| 89 | $3854.44 \pm 0.06$ | $1.000 \pm 0.060$ |  |  |
| 90 | $3858.40 \pm 0.05$ | $0.640 \pm 0.050$ | CIV $\lambda 1548$ | $z=1.49218$ |
| 91 | $3861.40 \pm 0.12$ | $0.380 \pm 0.230$ |  |  |
| 92 | $3863.95 \pm 1.06$ | $0.560 \pm 0.300$ | CIV $\lambda 1550$ | $z=1.49163$ |
| 93 | $3869.87 \pm 0.05$ | $1.300 \pm 0.060$ |  |  |
| 94 | $3873.38 \pm 0.04$ | $0.960 \pm 0.050$ |  |  |




|  |  | 080．0干0970 | ［1．0728．8098 | I¢ |
| :---: | :---: | :---: | :---: | :---: |
|  <br> Z08ちて＇I $=z 8 \mathrm{EGIY}$ ND |  | 080．0才02t0 | 2007E¢9888 | $0 ¢$ |
|  |  | $0150 \mp 0160$ | 60070F08ヶ¢ | 62 |
|  | LILO9＇t＝z VEETY IDP | 09\％ $0 \mp 02 \varepsilon^{\prime} \mathrm{z}$ | LI＇0干te＇LLEE | 87 |
|  |  |  | U＇0干67＇ 9 ¢ | $2 \%$ |
|  |  | 00\％ $0 \mp 0868$ | 800才69＇z¢t¢ | 97 |
|  |  | 02107076 | 200F0g Lite | 97 |
|  |  |  | 90079868\＆8 | $\dagger z$ |
|  |  | $060.0 \mp 085^{\circ} 0$ | 900769 ャてャ¢ | $\varepsilon z$ |
|  |  | $0 \mathrm{bl} 0 \mp 0290$ |  | 72 |
|  |  | 091070ヶ2．0 | 91＇0干98＇\＆88¢ | IZ |
|  |  | $09^{\circ} 0 \mp 088^{\circ} 0$ | I＇0キマ¢＇LLE¢ | $0 \overline{1}$ |
|  |  | 00ヶ0干0968 | 910干ャ600z\＆ | 61 |
|  |  | $061^{\circ} \mathrm{O} 0249^{\circ} \mathrm{I}$ | \＆10キ02 $718 ¢$ | 81 |
|  |  | 02F0干080＇z | 1ヵ．07L8 1088 | 21 |
|  |  | 097．0〒092． | 070才198Lzを | 91 |
|  |  | 0z\％ $0 \mp 026^{\prime}$ I |  | 9I |
|  |  | OST $0 \mp 0900$ | 210才982988 | tI |
|  |  | 0LI0¢0¢\％I | 600702．69z8 | $\varepsilon I$ |
|  |  |  |  | ZI |
|  |  | 0710 0 ¢0680 |  | II |
|  |  | $0110 \mp 0890$ | 90．0干98．6ъて¢ | 0I |
|  |  | 021070290 | 80．0干¢\％9ちを8 | 6 |
|  |  | 007．0¢06\％ | $910 \pm 90$ ¢ъて¢ | 8 |
|  |  | $000^{\circ} \mathrm{O} 09990$ | ャ0．0才6188 88 | 1 |
|  |  | $088^{\circ} 0 \mp 079^{\circ}$ |  | 9 |
|  |  | OLI $0 \mp 02 L^{\circ}$ | 20．0才て＇6zze | q |
| CII PqTssod | ноиұеэу！ихар | （y）${ }^{\mathrm{Y}} \mathrm{M}$ | ${ }^{\text {890 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



| $69800^{\prime} z=z$ LEOIY INO |  | 180．07 $2888^{\circ} 0$ | 97．0干29．0t98 | 8 |
| :---: | :---: | :---: | :---: | :---: |
|  | L¢809 $2=z$ 980t\％IID | 8010才072\％ | Z7＇0干06：¢¢98 | 2 |
|  |  | 9900才18ヶ\％ | 60．0干85＇9798 | 9 |
|  |  | z910才662＇I | ti．0才8t＇6198 | g |
|  |  | 020．0才192．I | ャ0．078L¢198 | － |
|  |  | ¢REOFG86\％ | LIO耳7\％＇1098 | $\varepsilon$ |
|  | $61809^{\prime} Z=z \mathcal{S}^{\prime}$ T |  | $80.0 \mp 858698$ | $\checkmark$ |
|  | $8 \mathrm{~L} 28 \mathrm{t}^{\circ} \mathrm{Z}=z \mathrm{~g}^{\prime} \mathrm{T}$ | ャ010キモ00\％ | L0．0788．9298 | 1 |
| $986+28810$ |  |  |  |  |
| L6z98＇I＝z 8091Y $\mathrm{IP}^{\text {P }} \mathrm{d}$ |  | 02100．09\％z |  | $8{ }^{\text {8 }}$ |
|  |  | 00t0干098＊ | 91071c．920t | Lt |
|  |  | 007．0才0¢ 20 | It＇0才¢\％＇z\％0t | 9t |
|  |  | 080．0〒088．0 | 020719＇8868 | $\mathrm{c}^{\text {b }}$ |
|  | 6SILJ＇t＝z 0gGIY AD | 060．0才0z0＇ | 010788＇z888 | 切 |
|  | ¢91L＇t $=z 8 \mathrm{bGTY}$ 人ID | 080．070Iて＇I | 90076¢9788 | $\varepsilon \square$ |
|  | Z6988＇ı＝z ๖¢¢โY ID | 001070L20 |  | 7b |
|  |  | 060．0干00 0 | L＇0干10．0928 | $\underline{\text { L }}$ |
|  |  | 080，07068．0 |  | $0{ }^{\circ}$ |
|  |  | 0200才0 ${ }^{\circ} 0$ | 60．0キャ！＇ท998 | 68 |
| LセZGE＇I＝z 0gcir Mip | 09009 $1=z$ 20tIY 1 I！ | 0ヶT070L20 | 620790＇8t98 | 88 |
|  |  | 0600¢0960 | 210¢697698 | 28 |
|  |  |  | LI＇0干LL＇ャて98 | 98 |
|  | 9p6I¢ $0=z$ Z887Y IIP | 020070180 | 910 0 ¢¢¢ 0798 | 98 |
|  |  | 090＇0キ001＇ | 800FLLVLS8 | ¢¢ |
|  |  | 0ヶ00070t90 | 900FLI＇6998 | \＆ |
|  |  | $090.0 \mp 098.0$ | 900才ャレ09s¢ | 78 |
| C．I Pq！${ }^{\text {S }}$ | ио！บеэч！บиәрI | （V）${ }^{\mathrm{r}} \mathrm{M}$ | ${ }^{\text {s90 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |


Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 9 | $3649.64 \pm 0.12$ | $0.504 \pm 0.069$ |  |  |
| 10 | $3653.30 \pm 0.03$ | $1.662 \pm 0.067$ |  |  |
| 11 | $3657.67 \pm 0.03$ | $3.756 \pm 0.093$ |  |  |
| 12 | $3665.54 \pm 0.03$ | $2.842 \pm 0.066$ |  |  |
| 13 | $3681.79 \pm 0.05$ | $1.873 \pm 0.078$ |  |  |
| 14 | $3705.88 \pm 0.05$ | $1.351 \pm 0.072$ |  |  |
| 15 | $3713.35 \pm 0.06$ | $1.146 \pm 0.076$ |  |  |
| 16 | $3718.74 \pm 0.05$ | $0.935 \pm 0.079$ |  |  |
| 17 | $3722.30 \pm 0.30$ | $0.658 \pm 0.140$ |  |  |
| 18 | $3749.18 \pm 0.08$ | $0.450 \pm 0.060$ |  |  |
| 19 | $3755.54 \pm 0.04$ | $0.770 \pm 0.052$ |  |  |
| 20 | $3762.04 \pm 0.03$ | $2.010 \pm 0.066$ |  |  |
| 21 | $3779.56 \pm 0.13$ | $0.359 \pm 0.063$ |  |  |
| 22 | $3782.54 \pm 0.03$ | $1.663 \pm 0.057$ |  |  |
| 23 | $3796.03 \pm 0.04$ | $0.210 \pm 0.091$ |  |  |
| 24 | $3798.60 \pm 0.08$ | $0.580 \pm 0.058$ |  |  |
| 25 | $3803.20 \pm 0.10$ | $0.784 \pm 0.070$ | NII $\lambda 1083$ | $z=2.50851$ |
| 26 | $3812.60 \pm 0.04$ | $3.380 \pm 0.101$ |  |  |
| 27 | $3815.99 \pm 0.04$ | $1.188 \pm 0.075$ |  |  |
| 28 | $3822.09 \pm 0.10$ | $0.306 \pm 0.053$ |  |  |
| 29 | $3827.78 \pm 0.42$ | $0.838 \pm 0.187$ |  |  |
| 30 | $3833.94 \pm 0.11$ | $0.609 \pm 0.070$ |  |  |
| 31 | $3838.13 \pm 0.04$ | $1.980 \pm 0.070$ |  |  |
| 32 | $3843.82 \pm 0.17$ | $0.262 \pm 0.060$ |  |  |
| 33 | $3852.12 \pm 0.06$ | $2.165 \pm 0.086$ |  |  |
| 34 | $3861.42 \pm 0.12$ | $0.484 \pm 0.065$ |  |  |
| 35 | $3864.89 \pm 0.05$ | $0.644 \pm 0.053$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 36 | $3868.78 \pm 0.03$ | $1.955 \pm 0.060$ |  |  |
| 37 | $3878.57 \pm 0.09$ | $1.007 \pm 0.075$ |  |  |
| 38 | $3882.75 \pm 0.06$ | $0.348 \pm 0.044$ |  |  |
| 39 | $3900.39 \pm 0.12$ | $3.315 \pm 0.218$ |  |  |
| 40 | $3908.85 \pm 0.05$ | $2.817 \pm 0.135$ |  |  |
| 41 | $3919.84 \pm 0.04$ | $1.048 \pm 0.061$ |  |  |
| 42 | $3922.60 \pm 0.07$ | $0.909 \pm 0.068$ |  |  |
| 43 | $3933.06 \pm 0.29$ | $0.689 \pm 0.123$ |  |  |
| 44 | $3952.66 \pm 0.06$ | $1.798 \pm 0.077$ |  |  |
| 45 | $3965.81 \pm 0.04$ | $2.162 \pm 0.068$ |  |  |
| 46 | $3971.50 \pm 0.15$ | $0.190 \pm 0.047$ |  |  |
| 47 | $3978.02 \pm 0.07$ | $0.631 \pm 0.053$ |  |  |
| 48 | $3988.21 \pm 0.03$ | $1.697 \pm 0.052$ |  |  |
| 49 | $3998.58 \pm 0.15$ | $0.832 \pm 0.079$ |  |  |
| 50 | $4014.73 \pm 0.20$ | $0.700 \pm 0.169$ |  |  |
| 51 | $4017.04 \pm 0.19$ | $0.872 \pm 0.174$ |  |  |
| 52 | $4020.91 \pm 0.04$ | $1.573 \pm 0.060$ |  |  |
| 53 | $4027.36 \pm 0.06$ | $2.002 \pm 0.082$ | FeII $\lambda 1143$ | $z=2.52280$ |
| 54 | $4033.21 \pm 0.05$ | $6.412 \pm 0.214$ | FeII $\lambda 1145 z=2.52267$ |  |
| 55 | $4037.95 \pm 0.03$ | $1.885 \pm 0.109$ |  |  |
| 56 | $4044.67 \pm 0.09$ | $0.320 \pm 0.050$ |  |  |
| 57 | $4056.13 \pm 0.02$ | $3.593 \pm 0.062$ |  |  |
| 58 | $4071.19 \pm 0.03$ | $2.436 \pm 0.056$ |  |  |
| 59 | $4076.05 \pm 0.04$ | $1.861 \pm 0.062$ |  |  |
| 60 | $4085.91 \pm 0.03$ | $4.968 \pm 0.117$ |  |  |
| 61 | $4090.10 \pm 0.05$ | $1.565 \pm 0.092$ |  |  |
| 62 | $4097.35 \pm 0.13$ | $5.393 \pm 0.356$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 63 | $4106.93 \pm 0.10$ | $0.622 \pm 0.058$ |  |  |
| 64 | $4116.22 \pm 0.06$ | $0.696 \pm 0.068$ |  |  |
| 65 | $4118.50 \pm 0.10$ | $0.646 \pm 0.073$ |  |  |
| 66 | $4131.19 \pm 0.11$ | $0.770 \pm 0.076$ |  |  |
| 67 | $4133.66 \pm 0.05$ | $0.704 \pm 0.064$ |  |  |
| 68 | $4137.94 \pm 0.06$ | $2.080 \pm 0.074$ |  |  |
| 69 | $4143.00 \pm 0.02$ | $3.496 \pm 0.051$ |  |  |
| 70 | $4151.02 \pm 0.02$ | $3.328 \pm 0.050$ |  |  |
| 71 | $4160.38 \pm 0.03$ | $1.743 \pm 0.044$ |  |  |
| 72 | $4172.60 \pm 0.05$ | $6.980 \pm 0.150$ |  |  |
| 73 | $4174.93 \pm 0.03$ | $0.398 \pm 0.026$ |  |  |
| 74 | $4176.19 \pm 0.03$ | $0.678 \pm 0.032$ |  |  |
| 75 | $4178.13 \pm 0.04$ | $1.531 \pm 0.083$ |  |  |
| 76 | $4183.44 \pm 0.57$ | $0.902 \pm 0.257$ |  |  |
| 77 | $4186.42 \pm 0.04$ | $0.556 \pm 0.089$ |  |  |
| 78 | $4190.66 \pm 0.11$ | $1.308 \pm 0.112$ |  |  |
| 79 | $4196.96 \pm 0.41$ | $0.507 \pm 0.110$ |  |  |
| 80 | $4203.04 \pm 0.04$ | $2.509 \pm 0.062$ |  |  |
| 81 | $4212.96 \pm 0.02$ | $0.868 \pm 0.031$ |  |  |
| 82 | $4218.18 \pm 0.03$ | $0.916 \pm 0.035$ |  |  |
| 83 | $4222.79 \pm 0.04$ | $0.352 \pm 0.029$ |  |  |
| 84 | $4226.46 \pm 0.04$ | $0.469 \pm 0.031$ |  |  |
| 85 | $4230.10 \pm 0.02$ | $1.270 \pm 0.033$ |  |  |
| 86 | $4238.68 \pm 0.09$ | $1.205 \pm 0.066$ | Ly $\alpha z=2.48670$ |  |
| 87 | $4244.50 \pm 0.04$ | $0.627 \pm 0.032$ |  |  |
| 88 | $4249.52 \pm 0.01$ | $2.811 \pm 0.034$ | SiIII $\lambda 1206$ |  |
| 89 | $4256.11 \pm 0.02$ | $1.674 \pm 0.032$ |  |  |


|  |  | 001．0干09\％＇0 | \＆107LI＇I8LE | 21 |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 009．0干089 ${ }^{\circ}$ | LGOF 82.6928 | 91 |
|  |  | $0 ¢ 70$ O09 \％ 0 |  | ¢I |
|  |  | 0810干0¢0 1 | 60072866LE | bI |
|  |  |  | 90．0干98．97LE | $\varepsilon I$ |
|  |  |  | 910780－28LE | ZI |
|  |  | 0210干016． | 600781 | II |
|  |  | 09I0干0¢0 I | 600\％戸¢＇8898 | 0I |
|  |  | 081．0干0z8＇I | 600728：8798 | 6 |
|  |  | 091．0干069 1 | 900\％ $999^{\circ} \mathrm{Iz98}$ | 8 |
|  |  |  | 010干90．0098 | $L$ |
|  |  | $087^{\circ} 0 \mp 09 L^{\circ} \mathrm{L}$ | －10FIE6898 | 9 |
|  |  | 0970才0L9＇Z | て107¢9＇1998 | g |
|  |  | $007^{\circ} 0 \mp 060^{\circ} \mathrm{I}$ | It．0干69．LLDE | $\checkmark$ |
|  |  | $097^{\circ} 0 \mp 066^{\circ} 0$ | 8107996968 | $\varepsilon$ |
|  | ${ }^{6} 6798.7=z g \mathcal{S}_{T}$ | 0620 0 ¢08 ${ }^{\circ} \mathrm{L}$ | \＆7．0干GL．6bb | $\zeta$ |
|  |  | 069．0¢029\％ |  | 1 |
|  | 980－97¢ ${ }^{\text {O }}$ |  |  |  |
|  |  | 260．0干897\％ |  | 26 |
|  |  | 9800 $09700^{\circ} \mathrm{Z}$ | 200才10888t | 96 |
|  |  | Z800 $0^{\circ} 628^{\circ} 0$ | 010 0 ¢96．96\％t | 96 |
|  | L2879 ${ }^{\circ} \mathrm{Z}=2$ DКТ | 8も0．0干口I6． | 80．0耳\＆8．68で | 6 |
|  |  |  | $10.0 \mp 09 \mathrm{z87} \mathrm{\%}$ | 86 |
|  |  |  | 800 0 ¢ $28827 t$ | Z6 |
|  |  | 6700 ¢ 128.7 |  | I6 |
|  |  | 080．07088．0 | 800円 $26.097 *$ | 06 |
| ${ }^{\text {C／I Plqussod }}$ | ио！̣еоч！${ }^{\text {a }}$ | （ $\mathrm{y}^{\text {r }}$＇$M$ | ${ }^{\text {sq9 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{ON}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 18 | $3783.35 \pm 0.05$ | $0.900 \pm 0.100$ |  |  |
| 19 | $3793.46 \pm 0.13$ | $0.630 \pm 0.110$ |  |  |
| 20 | $3804.00 \pm 0.12$ | $1.410 \pm 0.150$ |  |  |
| 21 | $3846.97 \pm 0.09$ | $1.680 \pm 0.140$ |  |  |
| 22 | $3852.41 \pm 0.10$ | $0.870 \pm 0.110$ |  |  |
| 23 | $3856.49 \pm 0.07$ | $0.460 \pm 0.080$ |  |  |
| 24 | $3863.67 \pm 0.10$ | $0.620 \pm 0.100$ |  |  |
| 25 | $3880.35 \pm 0.08$ | $1.910 \pm 0.130$ |  |  |
| 26 | $3902.89 \pm 0.08$ | $0.930 \pm 0.090$ |  |  |
| 27 | $3906.33 \pm 0.08$ | $0.510 \pm 0.080$ |  |  |
| 28 | $3911.88 \pm 0.24$ | $0.470 \pm 0.110$ |  |  |
| 29 | $3925.20 \pm 0.07$ | $0.880 \pm 0.080$ |  |  |
| 30 | $3941.90 \pm 0.10$ | $0.650 \pm 0.080$ |  |  |
| 31 | $3954.37 \pm 0.13$ | $0.740 \pm 0.100$ |  |  |
| 32 | $3965.04 \pm 0.05$ | $2.120 \pm 0.090$ | Ly $\alpha=2.26160$ |  |
| 33 | $3968.99 \pm 0.14$ | $0.730 \pm 0.090$ |  |  |
| 34 | $3976.09 \pm 0.11$ | $0.590 \pm 0.070$ |  |  |
| 35 | $3991.34 \pm 0.07$ | $1.380 \pm 0.080$ |  |  |
| 36 | $3996.90 \pm 0.04$ | $1.670 \pm 0.060$ |  |  |
| 37 | $4006.74 \pm 0.06$ | $1.770 \pm 0.110$ |  |  |
| 38 | $4010.55 \pm 0.07$ | $1.600 \pm 0.090$ |  |  |
| 39 | $4017.37 \pm 0.42$ | $0.980 \pm 0.300$ |  |  |
| 40 | $4021.73 \pm 0.29$ | $0.410 \pm 0.190$ |  |  |
| 41 | $4030.35 \pm 0.16$ | $0.480 \pm 0.060$ |  |  |
| 42 | $4043.08 \pm 0.08$ | $1.360 \pm 0.070$ | MgII $\lambda 2796 \quad z=0.44584$ |  |
| 43 | $4051.09 \pm 0.08$ | $1.030 \pm 0.090$ |  |  |
| 44 | $4054.31 \pm 0.21$ | $0.520 \pm 0.090$ | MgII $\lambda 2803 \quad z=0.44614$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 45 | $4066.89 \pm 0.04$ | $0.240 \pm 0.030$ | Ly $\alpha z=2.36300$ |  |
| 46 | $4071.22 \pm 0.06$ | $0.200 \pm 0.030$ |  |  |
| 47 | $4083.86 \pm 0.10$ | $1.130 \pm 0.080$ |  |  |
| 48 | $4088.31 \pm 0.05$ | $1.910 \pm 0.060$ |  |  |
| 49 | $4117.46 \pm 0.10$ | $0.190 \pm 0.040$ |  |  |
| Q 1358+115 |  |  |  |  |
| 1 | $3565.43 \pm 1.02$ | $0.060 \pm 0.270$ |  |  |
| 2 | $3567.93 \pm 0.35$ | $3.470 \pm 0.660$ | $\mathrm{Ly} \beta z=2.47845$ |  |
| 3 | $3587.26 \pm 0.18$ | $1.950 \pm 0.360$ | $\mathrm{Ly} \beta z=2.49730$ |  |
| 4 | $3593.55 \pm 0.35$ | $3.770 \pm 0.800$ | Fell $\lambda 2382 z=0.50814$ |  |
| 5 | $3615.05 \pm 0.24$ | $2.520 \pm 0.420$ |  |  |
| 6 | $3631.84 \pm 0.41$ | $2.100 \pm 0.530$ |  |  |
| 7 | $3637.65 \pm 0.28$ | $3.610 \pm 0.680$ | $\mathrm{Ly} \beta z=2.54642$ |  |
| 8 | $3647.52 \pm 0.16$ | $1.234 \pm 0.296$ |  |  |
| 9 | $3654.75 \pm 0.17$ | $1.840 \pm 0.270$ | Ly $\beta z=2.56309$ |  |
| 10 | $3672.01 \pm 0.19$ | $4.070 \pm 0.480$ | $\mathrm{Ly} \beta z=2.57992$ |  |
| 11 | $3688.75 \pm 0.25$ | $5.830 \pm 0.930$ | OVI $\lambda 1031 z=2.57453$ |  |
| 12 | $3694.24 \pm 0.19$ | $5.260 \pm 0.650$ | OVI $\lambda 1031 z=2.57994$ |  |
| 13 | $3709.44 \pm 0.14$ | $3.180 \pm 0.300$ | OVI $\lambda 1037 z=2.57496$ |  |
| 14 | $3714.48 \pm 0.17$ | $5.220 \pm 0.570$ | OVI $\lambda 1037 z=2.57982$ |  |
| 15 | $3719.27 \pm 0.13$ | $2.240 \pm 0.230$ |  |  |
| 16 | $3723.05 \pm 0.10$ | $0.710 \pm 0.150$ |  |  |
| 17 | $3757.03 \pm 0.20$ | $1.330 \pm 0.230$ |  |  |
| 18 | $3762.37 \pm 0.11$ | $0.650 \pm 0.150$ |  |  |
| 19 | $3765.56 \pm 0.14$ | 0.880 $\pm 0.180$ |  |  |
| 20 | $3772.14 \pm 0.14$ | $1.500 \pm 0.210$ |  |  |


|  | LLGLV＇Z＝z 0¢ $T$ | 081．07062． |  | 97 |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 00707012． 8 |  | C |
|  |  | 0¢10才069＊0 |  | 㠶 |
|  |  | 0zI＇0干092＇0 | 21079603It | $\varepsilon \square$ |
|  | Z8゙じでて＝z 00GIY IN | 02I0 $0 ¢ 000 \cdot 8$ | 80\％ $0 \mp 62 \cdot 260$ b | 7\％ |
|  |  | 0910干068＊0 |  | It |
|  |  | 09107082．1 | 010干以゙も800 | 0b |
|  |  | 0610¢09\％ | 110781．080家 | 68 |
|  |  | $0900 \mp 080 \checkmark$ 亿 | \＆ $7^{\circ} 0 \mp 56 \cdot 620 *$ | 88 |
| LL9Gg $\%=z$ gbily IIPd |  | $0960 \mp 00 \%^{\circ} \mathrm{Z}$ | 17：0干67：720\％ | LE |
| －19Gg＇z＝z ¢bIIY IIPd |  |  |  |  |
| 9IGİて $=z$ 06IIY II！S |  | 061．07098．0 |  | 98 |
|  |  | 080070890 | 900干68090才 | ¢ $¢$ |
|  |  | 08107080 ${ }^{\circ}$ | 210712．900 | も¢ |
|  |  | $09 \%^{\circ} 0 \mp 066^{\prime}$ I | \＆100F28．7ヶ0t | \＆ |
|  |  | 072．0干096＇Z | $60.0 \mp 26.880 \downarrow$ | 78 |
|  |  | 0010干0ヶ9\％ | 90．0干1ヶ．0668 | I $\varepsilon$ |
|  |  | 0910干076．0 |  | 0¢ |
|  |  | 091070880 | て1072も 2168 | 62 |
|  |  | $0 \mathrm{t} 0 \mp 099 \cdot 0$ | ［1．0干02．9688 | 87 |
|  |  | 0LI＇0干098．0 |  | $2 z$ |
|  |  | 0¢z＇0干0¢9＇L | \＆70F27：2888 | 97 |
|  |  | 087＇0干009 ${ }^{\text {－}}$ | \＆10719＊8788 | 96 |
|  |  | 091．0干0¢z＇ | 010于9「6188 | bz |
|  |  | 0¢I．0干089＊0 | II＇0干LE＇1088 | \＆Z |
|  |  | 0180701900 | 810776．8628 | Z |
|  |  | 02\％ 0 F096 ${ }^{\text {L }}$ | 08．0干LZ＇1628 | 12 |
|  | иопреэу！ | （ $)^{\text {r }} \mathrm{M}$ | ${ }^{\text {sqo }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 47 | $4164.34 \pm 0.06$ | $3.240 \pm 0.160$ |  |  |
| 48 | $4172.47 \pm 0.08$ | $0.790 \pm 0.100$ |  |  |
| 49 | $4175.71 \pm 0.10$ | $0.580 \pm 0.100$ |  |  |
| 50 | $4183.01 \pm 0.10$ | $0.920 \pm 0.110$ |  |  |
| 51 | $4192.71 \pm 0.07$ | $2.610 \pm 0.160$ |  |  |
| 52 | $4200.98 \pm 0.07$ | $0.970 \pm 0.100$ |  | MgII $\lambda 2803 z=0.50803$ |
| 53 | $4214.54 \pm 0.10$ | $0.820 \pm 0.100$ |  |  |
| 54 | $4217.93 \pm 0.05$ | $1.530 \pm 0.100$ | MgII $\lambda 2796 z=0.50837$ |  |
| 55 | $4227.82 \pm 0.09$ | $5.060 \pm 0.280$ | Ly $\alpha z=2.47776$ | SiII $\lambda 1190 z=2.56290$ |
| 56 | $4233.65 \pm 0.07$ | $4.340 \pm 0.190$ |  | SiII $\lambda 1193 z=2.55616$ |
| 57 | $4238.54 \pm 0.76$ | $1.050 \pm 0.700$ |  |  |
| 58 | $4241.34 \pm 0.42$ | $0.260 \pm 0.430$ |  |  |
| 59 | $4243.53 \pm 0.31$ | $0.440 \pm 0.170$ |  |  |
| 60 | $4251.01 \pm 0.06$ | $4.010 \pm 0.150$ | Ly $\alpha z=2.49684$ |  |
| 61 | $4257.04 \pm 0.05$ | $2.280 \pm 0.100$ |  |  |
| 62 | $4266.39 \pm 0.06$ | $1.400 \pm 0.090$ | NI $\lambda 1200 z=2.55532$ |  |
| 63 | $4290.41 \pm 0.08$ | $0.200 \pm 0.040$ | SiIII $\lambda 1206 z=2.55608$ |  |
| 64 | $4296.63 \pm 0.08$ | $0.350 \pm 0.050$ |  |  |
| 65 | $4303.01 \pm 0.12$ | $1.410 \pm 0.110$ | MgI $\lambda 2853 z=0.50826$ |  |
| 66 | $4307.78 \pm 0.03$ | $1.500 \pm 0.060$ |  |  |
| 67 | $4312.13 \pm 0.05$ | $2.870 \pm 0.100$ | Ly $\alpha z=2.54712$ |  |
| 68 | $4315.89 \pm 0.09$ | $0.480 \pm 0.060$ |  |  |
| 69 | $4322.75 \pm 0.06$ | $2.300 \pm 0.090$ | Ly $\alpha z=2.55586$ |  |
| 70 | $4331.43 \pm 0.03$ | $3.420 \pm 0.080$ | Ly $\alpha z=2.56299$ |  |
| 71 | $4347.64 \pm 0.13$ | $6.720 \pm 0.490$ | Ly $\alpha z=2.57633$ |  |
| 72 | $4351.61 \pm 0.08$ | $6.320 \pm 0.310$ | Ly $\alpha z=2.57959$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | $\mathrm{Q} 1406+492$ |  |
| 1 | $3222.23 \pm 0.03$ | $1.120 \pm 0.100$ |  |  |
| 2 | $3235.49 \pm 0.11$ | $0.560 \pm 0.130$ | $\mathrm{Ly} \beta$ | $z=2.15435$ |
| 3 | $3237.32 \pm 0.11$ | $0.650 \pm 0.130$ |  |  |
| 4 | $3250.16 \pm 0.16$ | $2.260 \pm 0.240$ |  |  |
| 5 | $3254.98 \pm 0.11$ | $2.700 \pm 0.230$ |  |  |
| 6 | $3257.81 \pm 0.10$ | $0.510 \pm 0.140$ |  |  |
| 7 | $3265.92 \pm 0.08$ | $3.170 \pm 0.230$ | CII $\lambda 1334 \quad z=1.44723$ |  |
| 8 | $3269.70 \pm 0.28$ | $1.170 \pm 0.280$ |  |  |
| 9 | $3275.17 \pm 0.04$ | $0.630 \pm 0.070$ |  |  |
| 10 | $3280.78 \pm 0.36$ | $0.990 \pm 0.250$ |  |  |
| 11 | $3285.51 \pm 0.19$ | $3.110 \pm 0.370$ |  |  |
| 12 | $3290.55 \pm 0.11$ | $2.090 \pm 0.190$ |  |  |
| 13 | $3299.33 \pm 0.37$ | $1.760 \pm 0.380$ |  |  |
| 14 | $3309.02 \pm 0.16$ | $0.690 \pm 0.160$ |  |  |
| 15 | $3318.83 \pm 0.07$ | $1.430 \pm 0.160$ |  |  |
| 16 | $3323.07 \pm 0.15$ | $1.850 \pm 0.230$ |  |  |
| 17 | $3327.99 \pm 0.07$ | $0.660 \pm 0.230$ |  |  |
| 18 | $3330.33 \pm 0.25$ | $2.230 \pm 0.410$ |  |  |
| 19 | $3340.67 \pm 0.09$ | $3.930 \pm 0.230$ |  |  |
| 20 | $3345.48 \pm 0.05$ | $1.640 \pm 0.130$ |  |  |
| 21 | $3366.70 \pm 0.20$ | $0.650 \pm 0.150$ |  |  |
| 22 | $3373.53 \pm 0.08$ | $0.500 \pm 0.110$ |  |  |
| 23 | $3384.58 \pm 0.03$ | $2.180 \pm 0.110$ |  |  |
| 24 | $3391.03 \pm 0.16$ | $1.360 \pm 0.180$ | SiIV $\lambda 1393$ | $z=1.43301$ |
| 25 | $3402.15 \pm 0.10$ | $0.820 \pm 0.120$ |  |  |
| 26 | $3411.15 \pm 0.09$ | $2.450 \pm 0.170$ | SiIV $\lambda 1402$ | $z=1.43172$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :--- |
| 27 | $3424.35 \pm 0.15$ | $1.030 \pm 0.150$ |  |  |
| 28 | $3434.93 \pm 0.07$ | $2.480 \pm 0.160$ |  |  |
| 29 | $3440.32 \pm 0.03$ | $1.240 \pm 0.140$ |  |  |
| 30 | $3444.62 \pm 0.92$ | $2.080 \pm 0.800$ |  |  |
| 31 | $3447.18 \pm 0.08$ | $0.790 \pm 0.280$ |  |  |
| 32 | $3449.29 \pm 0.05$ | $2.600 \pm 0.370$ |  |  |
| 33 | $3452.16 \pm 0.06$ | $1.510 \pm 0.140$ |  |  |
| 34 | $3460.57 \pm 0.16$ | $0.910 \pm 0.150$ |  |  |
| 35 | $3464.17 \pm 0.08$ | $0.360 \pm 0.080$ |  |  |
| 36 | $3502.45 \pm 0.15$ | $1.390 \pm 0.160$ |  |  |
| 37 | $3514.96 \pm 0.18$ | $0.620 \pm 0.130$ |  |  |
| 38 | $3519.64 \pm 0.08$ | $0.520 \pm 0.090$ |  |  |
| 39 | $3543.15 \pm 0.06$ | $1.570 \pm 0.120$ |  |  |
| 40 | $3549.04 \pm 0.07$ | $2.010 \pm 0.130$ |  |  |
| 41 | $3589.85 \pm 0.06$ | $1.700 \pm 0.110$ |  |  |
| 42 | $3607.85 \pm 0.05$ | $2.430 \pm 0.110$ |  |  |
| 43 | $3619.52 \pm 0.11$ | $1.160 \pm 0.130$ |  |  |
| 44 | $3631.31 \pm 0.12$ | $0.630 \pm 0.110$ |  |  |
| 45 | $3650.04 \pm 0.07$ | $1.920 \pm 0.120$ |  |  |
| 46 | $3660.93 \pm 0.06$ | $0.490 \pm 0.070$ |  |  |
| 47 | $3673.55 \pm 0.02$ | $3.690 \pm 0.080$ |  |  |
| 48 | $3686.62 \pm 0.06$ | $1.510 \pm 0.100$ |  |  |
| 49 | $3703.44 \pm 0.17$ | $0.600 \pm 0.100$ |  |  |
| 50 | $3716.18 \pm 0.07$ | $0.290 \pm 0.050$ |  |  |
| 51 | $3731.52 \pm 0.15$ | $0.830 \pm 0.120$ |  |  |
| 52 | $3736.06 \pm 0.06$ | $3.120 \pm 0.130$ | SiII $\lambda 1526$ | $z=1.44713$ |
| 53 | $3740.70 \pm 0.07$ | $2.140 \pm 0.110$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {nbs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 54 | $3744.98 \pm 0.06$ | $1.480 \pm 0.100$ |  |  |
| 55 | $3748.23 \pm 0.19$ | $0.560 \pm 0.120$ |  |  |
| 56 | $3751.20 \pm 0.07$ | $0.380 \pm 0.080$ |  |  |
| 57 | $3758.92 \pm 0.04$ | $5.110 \pm 0.150$ |  |  |
| 58 | $3766.86 \pm 0.04$ | $0.810 \pm 0.050$ | CIV $\lambda 1548 z=1.43305$ |  |
| 59 | $3770.13 \pm 0.06$ | $0.640 \pm 0.050$ |  |  |
| 60 | $3773.16 \pm 0.09$ | $0.180 \pm 0.040$ | CIV $\lambda 1550 z=1.43308$ |  |
| 61 | $3780.79 \pm 0.03$ | $1.160 \pm 0.040$ |  |  |
| 62 | $3788.53 \pm 0.03$ | $2.650 \pm 0.060$ | CIV $\lambda 1548 z=1.44705$ |  |
| 63 | $3792.08 \pm 0.06$ | $0.310 \pm 0.040$ |  |  |
| 64 | $3794.94 \pm 0.05$ | $1.520 \pm 0.060$ | CIV $\lambda 1550 z=1.44712$ |  |
| 65 | $3799.15 \pm 0.05$ | $0.340 \pm 0.040$ |  |  |
| 66 | $3801.25 \pm 0.07$ | $0.450 \pm 0.050$ |  |  |
| 67 | $3813.28 \pm 0.11$ | $0.330 \pm 0.040$ |  |  |
| 68 | $3819.85 \pm 0.02$ | $0.920 \pm 0.030$ |  |  |
| 69 | $3824.13 \pm 0.11$ | $0.150 \pm 0.030$ |  |  |
| 70 | $3834.26 \pm 0.03$ | $0.650 \pm 0.030$ | Ly $\alpha z=2.15403$ |  |
| 71 | $3909.72 \pm 0.04$ | $1.220 \pm 0.050$ | CIV $\lambda 1548 z=1.52532$ |  |
| 72 | $3916.29 \pm 0.04$ | $0.800 \pm 0.050$ | CIV $\lambda 1550 z=1.52537$ |  |
| 73 | $3936.55 \pm 0.04$ | $0.510 \pm 0.040$ | FeII $\lambda 1608 z=1.44741$ |  |
| 74 | $4055.32 \pm 0.18$ | $0.490 \pm 0.090$ |  |  |
|  |  |  | Q $1408+009$ |  |
| 1 | $3227.73 \pm 0.21$ | $2.213 \pm 0.485$ | SiIV $\lambda 1393 z=1.31585$ |  |
| 2 | $3241.71 \pm 0.34$ | $2.407 \pm 0.600$ |  |  |
| 3 | $3248.54 \pm 0.35$ | $3.515 \pm 0.656$ | SiIV $\lambda 1402 z=1.31580$ | SiIII $\lambda 1206 z=1.69253$ |
| 4 | $3273.73 \pm 0.25$ | $3.105 \pm 0.476$ | Ly $\alpha=1.69294$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 5 | $3282.29 \pm 0.09$ | $7.544 \pm 0.554$ | $\mathrm{Ly} \beta$ | $z=2.19997$ |
| 6 | $3290.77 \pm 0.30$ | $1.929 \pm 0.450$ | $\mathrm{Ly} \beta$ | $z=2.20825$ |
| 7 | $3310.67 \pm 0.32$ | $3.274 \pm 0.523$ |  |  |
| 8 | $3319.97 \pm 0.22$ | $1.913 \pm 0.374$ |  |  |
| 9 | $3341.26 \pm 0.73$ | $4.052 \pm 0.818$ |  |  |
| 10 | $3362.64 \pm 0.39$ | $6.057 \pm 0.679$ | CII $\lambda 1334 z=1.51971$ |  |
| 11 | $3372.76 \pm 0.17$ | $1.936 \pm 0.357$ |  |  |
| 12 | $3378.90 \pm 0.53$ | $2.733 \pm 0.540$ |  | SiII $\lambda 1260 z=1.69250$ |
| 13 | $3393.69 \pm 0.42$ | $3.434 \pm 0.487$ |  |  |
| 14 | $3505.87 \pm 0.34$ | $3.173 \pm 0.443$ |  |  |
| 15 | $3529.48 \pm 0.12$ | $1.350 \pm 0.235$ |  |  |
| 16 | $3535.10 \pm 0.46$ | $1.661 \pm 0.418$ | SiII $\lambda 1526 z=1.31551$ |  |
| 17 | $3595.00 \pm 0.08$ | $5.829 \pm 0.347$ |  |  |
| 18 | $3601.24 \pm 0.19$ | $1.178 \pm 0.259$ |  |  |
| 19 | $3641.63 \pm 0.18$ | $4.497 \pm 0.388$ | Ly $\alpha z=1.99557$ |  |
| 20 | $3653.10 \pm 0.27$ | $6.466 \pm 0.488$ |  |  |
| 21 | $3676.95 \pm 0.28$ | $5.997 \pm 0.512$ |  |  |
| 22 | $3696.80 \pm 0.25$ | $2.660 \pm 0.357$ |  |  |
| 23 | $3710.66 \pm 0.20$ | $1.251 \pm 0.262$ |  |  |
| 24 | $3724.87 \pm 0.18$ | $1.100 \pm 0.245$ | FeII $\lambda 1608$ | $z=1.31581$ |
| 25 | $3774.53 \pm 0.55$ | $1.531 \pm 0.402$ | SiII $\lambda 1260 z=1.99466$ |  |
| 26 | $3801.16 \pm 0.42$ | $1.461 \pm 0.347$ |  |  |
| 27 | $3813.85 \pm 0.25$ | $1.719 \pm 0.293$ |  |  |
| 28 | $3843.49 \pm 0.34$ | $3.842 \pm 0.416$ | SilI $\lambda 1526 z=1.51750$ |  |
| 29 | $3859.56 \pm 0.40$ | $2.004 \pm 0.383$ | SilII $\lambda 1206 z=2.19897$ |  |
| 30 | $3865.30 \pm 0.25$ | $2.234 \pm 0.334$ |  |  |
| 31 | $3889.08 \pm 0.13$ | $5.199 \pm 0.282$ | Ly $\alpha z=2.19912$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathcal{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 32 | $3899.88 \pm 0.11$ | $2.741 \pm 0.213$ | Ly $\alpha z=2.20801$ | CIV $\lambda 1548 z=1.51897$ |
|  |  |  | OI $\lambda 1302 z=1.99491$ |  |
| 33 | $3906.56 \pm 0.22$ | $1.205 \pm 0.213$ | SilI $\lambda 1304 z=1.99498$ | CIV $\lambda 1550 z=1.51910$ |
| 34 | $3921.54 \pm 0.20$ | $2.245 \pm 0.232$ |  |  |
| 35 | $3954.86 \pm 0.16$ | $6.680 \pm 0.289$ |  |  |
| 36 | $3972.66 \pm 0.11$ | $1.808 \pm 0.129$ |  |  |
| 37 | $4029.50 \pm 0.43$ | $2.998 \pm 0.355$ |  |  |
| 38 | $4031.98 \pm 0.23$ | $1.147 \pm 0.210$ | SilI $\lambda 1260 \quad z=2.19891$ |  |
| 39 | $4040.79 \pm 0.16$ | $0.861 \pm 0.157$ |  |  |
| 40 | $4121.46 \pm 0.04$ | $1.552 \pm 0.138$ |  |  |
|  |  |  |  |  |
| 1 | $3209.86 \pm 0.17$ | $0.684 \pm 0.164$ |  |  |
| 2 | $3216.19 \pm 0.12$ | $1.734 \pm 0.184$ |  |  |
| 3 | $3224.84 \pm 0.17$ | $1.771 \pm 0.209$ |  |  |
| 4 | $3251.83 \pm 0.28$ | $0.791 \pm 0.167$ |  |  |
| 5 | $3257.48 \pm 0.27$ | $1.039 \pm 0.199$ |  |  |
| 6 | $3273.91 \pm 0.12$ | $3.479 \pm 0.276$ |  |  |
| 7 | $3278.89 \pm 0.16$ | $0.140 \pm 0.087$ | SilII $\lambda 1206 z=1.71768$ |  |
| 8 | $3281.38 \pm 0.97$ | $1.619 \pm 0.553$ |  |  |
| 9 | $3289.68 \pm 0.27$ | $2.300 \pm 0.389$ |  |  |
| 10 | $3304.23 \pm 0.08$ | $3.251 \pm 0.192$ | Ly $\alpha z=1.71803$ |  |
| 11 | $3314.50 \pm 0.38$ | $0.670 \pm 0.463$ |  |  |
| 12 | $3318.13 \pm 0.68$ | $1.184 \pm 0.811$ | SiII $\lambda 1526 z=1.17339$ |  |
| 13 | $3341.55 \pm 0.29$ | $0.962 \pm 0.193$ |  |  |
| 14 | $3352.40 \pm 0.17$ | $0.766 \pm 0.236$ |  |  |
| 15 | $3354.97 \pm 0.26$ | $1.272 \pm 0.290$ | Ly $\alpha z=1.75977$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 16 | $3360.93 \pm 0.08$ | $1.404 \pm 0.115$ |  |  |
| 17 | $3368.34 \pm 0.19$ | $1.407 \pm 0.180$ |  |  |
| 18 | $3386.10 \pm 0.64$ | $0.494 \pm 1.720$ |  |  |
| 19 | $3388.75 \pm 0.15$ | $0.385 \pm 0.081$ |  |  |
| 20 | $3395.85 \pm 0.24$ | $0.829 \pm 0.156$ |  |  |
| 21 | $3421.58 \pm 0.19$ | $0.538 \pm 0.122$ |  |  |
| 22 | $3427.61 \pm 0.21$ | $0.590 \pm 0.127$ |  |  |
| 23 | $3432.86 \pm 0.13$ | $1.176 \pm 0.133$ | SiIV $\lambda 1393 z=1.46303$ |  |
| 24 | $3437.98 \pm 0.12$ | $1.213 \pm 0.148$ |  |  |
| 25 | $3440.97 \pm 0.20$ | $0.520 \pm 0.125$ |  |  |
| 26 | $3445.85 \pm 0.07$ | $2.410 \pm 0.128$ |  |  |
| 27 | $3454.90 \pm 0.22$ | $0.561 \pm 0.115$ | SiIV $\lambda 1402 \quad z=1.46291$ |  |
| 28 | $3465.83 \pm 0.09$ | $1.074 \pm 0.094$ |  |  |
| 29 | $3492.20 \pm 0.04$ | $1.464 \pm 0.062$ |  |  |
| 30 | $3502.06 \pm 0.03$ | $1.992 \pm 0.060$ |  |  |
| 31 | $3521.70 \pm 0.06$ | $0.374 \pm 0.033$ |  |  |
| 32 | $3526.17 \pm 0.02$ | $1.240 \pm 0.034$ |  |  |
| 33 | $3529.61 \pm 0.09$ | $0.508 \pm 0.043$ | AlIII $\lambda 1854 z=0.90304$ |  |
| 34 | $3534.71 \pm 0.13$ | $0.163 \pm 0.034$ |  |  |
| 35 | $3539.44 \pm 0.21$ | $0.413 \pm 0.061$ | OI $\lambda 1302 z=1.71811$ |  |
| 36 | $3544.23 \pm 0.17$ | $0.553 \pm 0.068$ | AlIII $\lambda 1862 z=0.90264$ |  |
| 37 | $3663.44 \pm 0.09$ | $1.855 \pm 0.158$ |  |  |
| 38 | $3691.78 \pm 0.22$ | $0.955 \pm 0.218$ |  |  |
| 39 | $3695.36 \pm 0.24$ | $1.125 \pm 0.216$ |  |  |
| 40 | $3751.21 \pm 0.04$ | $0.984 \pm 0.091$ | CIV $\lambda 1548 \quad z=1.46306$ |  |
| 41 | $3813.31 \pm 0.05$ | $1.469 \pm 0.080$ |  |  |
| 42 | $3819.62 \pm 0.04$ | $1.149 \pm 0.070$ | CIV $\lambda 1550 z=1.46304$ |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 43 | $3851.70 \pm 0.16$ | $0.371 \pm 0.078$ |  |  |
| 44 | $4001.31 \pm 0.19$ | $0.393 \pm 0.086$ | CIV $\lambda 1548$ | $z=1.58448$ |
|  |  | Q 1422+231 |  |  |
| 1 | $4856.04 \pm 0.26$ | $0.300 \pm 0.070$ |  |  |
| 2 | $4862.68 \pm 0.05$ | $2.200 \pm 0.080$ |  |  |
| 3 | $4882.08 \pm 0.07$ | $4.170 \pm 0.190$ |  |  |
| 4 | $4889.96 \pm 0.06$ | $3.390 \pm 0.130$ |  |  |
| 5 | $4899.91 \pm 0.18$ | $2.270 \pm 0.280$ |  |  |
| 6 | $4907.10 \pm 0.05$ | $3.480 \pm 0.120$ |  |  |
| 7 | $4911.85 \pm 0.13$ | $0.910 \pm 0.110$ |  |  |
| 8 | $4919.97 \pm 0.08$ | $2.480 \pm 0.130$ |  |  |
| 9 | $4930.87 \pm 0.08$ | $0.910 \pm 0.060$ |  |  |
| 10 | $4940.03 \pm 0.04$ | $3.230 \pm 0.090$ |  |  |
| 11 | $4951.03 \pm 0.03$ | $3.580 \pm 0.090$ |  |  |
| 12 | $4957.35 \pm 0.43$ | $0.490 \pm 0.140$ |  |  |
| 13 | $4964.82 \pm 0.05$ | $1.630 \pm 0.090$ |  |  |
| 14 | $4968.68 \pm 0.05$ | $2.880 \pm 0.120$ |  |  |
| 15 | $4972.79 \pm 0.04$ | $3.780 \pm 0.100$ | Ly $\alpha z=3.09057$ |  |
| 16 | $4977.64 \pm 0.04$ | $4.170 \pm 0.100$ |  |  |
| 17 | $4981.98 \pm 0.18$ | $1.730 \pm 0.180$ |  |  |
| 18 | $4987.58 \pm 0.04$ | $0.960 \pm 0.050$ |  |  |
| 19 | $4995.53 \pm 0.09$ | $1.510 \pm 0.100$ |  |  |
| 20 | $5004.73 \pm 0.13$ | $0.370 \pm 0.060$ |  |  |
| 21 | $5008.38 \pm 0.04$ | $2.510 \pm 0.070$ |  |  |
| 22 | $5014.24 \pm 0.10$ | $0.630 \pm 0.070$ |  |  |
| 23 | $5018.60 \pm 0.05$ | $2.040 \pm 0.090$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 24 | $5025.52 \pm 0.05$ | $4.310 \pm 0.160$ |  |  |
| 25 | $5029.68 \pm 0.05$ | $4.480 \pm 0.150$ |  |  |
| 26 | $5039.02 \pm 0.03$ | $2.130 \pm 0.070$ |  |  |
| 27 | $5049.24 \pm 0.09$ | $0.470 \pm 0.060$ |  |  |
| 28 | $5055.00 \pm 0.05$ | $1.660 \pm 0.070$ |  |  |
| 29 | $5065.32 \pm 0.15$ | $0.380 \pm 0.070$ |  |  |
| 30 | $5069.64 \pm 0.11$ | $0.270 \pm 0.050$ |  |  |
| 31 | $5077.34 \pm 0.19$ | $0.340 \pm 0.070$ |  |  |
| 32 | $5087.28 \pm 0.12$ | $0.610 \pm 0.080$ |  |  |
| 33 | $5090.83 \pm 0.03$ | $1.760 \pm 0.060$ |  |  |
| 34 | $5095.30 \pm 0.04$ | $2.100 \pm 0.080$ |  |  |
| 35 | $5103.45 \pm 0.06$ | $1.400 \pm 0.080$ |  |  |
| 36 | $5107.68 \pm 0.19$ | $0.440 \pm 0.080$ |  |  |
| 37 | $5116.61 \pm 0.05$ | $1.240 \pm 0.070$ |  |  |
| 38 | $5123.48 \pm 0.09$ | $1.340 \pm 0.090$ |  |  |
| 39 | $5127.59 \pm 0.07$ | $1.150 \pm 0.080$ |  |  |
| 40 | $5137.47 \pm 0.04$ | $2.200 \pm 0.080$ | FeII $\lambda 1143 z=3.49383$ |  |
| 41 | $5140.58 \pm 0.12$ | $0.290 \pm 0.060$ |  |  |
| 42 | $5145.61 \pm 0.04$ | $2.500 \pm 0.090$ | FeIl $\lambda 1145 z=3.49422$ |  |
| 43 | $5149.12 \pm 0.10$ | $0.520 \pm 0.070$ |  |  |
| 44 | $5154.48 \pm 0.04$ | $2.150 \pm 0.080$ |  |  |
| 45 | $5157.47 \pm 0.05$ | $1.030 \pm 0.070$ | SiII $\lambda 1260$ | $z=3.09185$ |
| 46 | $5161.65 \pm 0.16$ | $0.690 \pm 0.090$ |  |  |
| 47 | $5166.21 \pm 0.05$ | $0.670 \pm 0.100$ |  |  |
| 48 | $5168.72 \pm 0.06$ | $2.500 \pm 0.160$ |  |  |
| 49 | $5171.69 \pm 0.07$ | $0.850 \pm 0.140$ |  |  |
| 50 | $5174.42 \pm 0.06$ | $2.930 \pm 0.180$ | SilI $\lambda 1190$ | $z=3.34673$ |


|  |  | 0ヵI 07096．0 | 0Z．0干98．898¢ | 12 |
| :---: | :---: | :---: | :---: | :---: |
|  | 70865 ${ }^{\circ}=z 06$ ITY II！S | 0zI＇0干0¢9\％ | 9007L9 8b\＆G | 92 |
|  |  | 0600709900 |  | $\underline{9}$ |
|  |  | 0LIOFOLE＇I | 80．0干61＇tを\＆¢ | － 2 |
| 78160 $\mathcal{E}=z$ Z0¢IY 10 | $96788 \cdot \mathcal{F}$ z $0 \kappa_{T}$ | 0GL0干0I9 $¢$ | 97＇0干ャ\％＇87¢¢ | $\varepsilon L$ |
|  | $00088 \mathrm{E}=z^{\text {OK}} \mathbf{T}$ | 08L0干019\％ | 9Z0干ャ9＇もて\＆¢ | 62 |
|  |  | 0800 ¢0bi＇t | ¢00720618¢ | IL |
|  |  | $060.0 \mp 080^{\circ}$ I | 90．0788．9IE¢ | 02 |
|  |  | 0910干079 $\frac{1}{}$ | 90．0干66．90\＆G | 69 |
|  |  | 0zI＇0干072＇0 | I $70 \mp$［6．86z¢ | 89 |
|  |  | 0LI0干060＇I | て10干0t 1689 | 29 |
|  | $969 \pm ¢ \varepsilon=z \quad 0 \kappa^{T}$ | 097．0干018＊ |  | 99 |
|  |  | 0910 0 0 $66 . \varepsilon$ | 90．0干¢6297c | ¢9 |
|  |  | $0600 \mp 069^{\circ} \mathrm{L}$ | 900\％ 08.2 gze | b9 |
|  |  | 0010 $0069^{\circ} \mathrm{Z}$ |  | ¢9 |
|  |  | 01I0干0¢İ | 9007¢ 6 6z¢ | 79 |
|  | ç97\＆ $\mathcal{C}=z$ 90ZIY IIIIS | 080．0干092． | 900才00＇しもてs | 19 |
|  |  | 0L0 0才0z90 | 80．0干96．0ъて¢ | 09 |
|  |  | 020．0干079 0 | L0＇0干80＇28Z9 | 69 |
|  |  | $080 \cdot 0$ ¢0¢\％ 1 | 900760＇IEzG | 89 |
|  |  | 06007028 I | 200706 5175 | L9 |
|  |  | 020．0干0L＊ 0 | 6007 26.2089 | 99 |
|  |  | 0¢「0F0z2．E | 900干90\％2079 | G9 |
|  |  |  | 8007ちL26IS | ¢¢ |
|  |  | 09\％ 0 干010 I | 切0干88．06IS | $\varepsilon ¢$ |
|  |  | $0270 \mp 0067$ | 61．0719．98IS | Z9 |
|  |  | 0110708id | 600709．2LIS | 19 |
| G＇I Plq！${ }^{\text {ssod }}$ |  | （y）${ }^{Y} M$ | ${ }^{\text {sq9 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{O}$ |



|  |  | 070 $7 \mp 06{ }^{\prime} \cdot 1$ |  | ャ0I |
| :---: | :---: | :---: | :---: | :---: |
| $26879 ¢=z 06$ ITY II！S | ¢0289 $\mathcal{E}=z 00 Z \mathrm{IY}$ IN | 001．0干0\＆¢ 0 | 6107ctib0cc | 80I |
|  |  | 0ヵ「 $0 \mp 0 ¢ 90$ | $81^{\circ} 0788.26 \mathrm{bS}$ | 201 |
|  |  | 0LI＇0干0Lb＇t |  | 101 |
|  |  | 0ZI．0干00L＇Z | $90.0 \mp 9168 \mathrm{bc}$ | 00I |
|  |  | 060．0干069\％0 | $80.0 \mp 70.98 \mathrm{tc}$ | 66 |
|  |  | $060 \cdot 708 \square^{\circ} 0$ | ¢1．0干6「18®G | 86 |
|  | 89¢ヶ¢ $¢=z 097$ IY II！S | $0070 \mp 0601$ | 0Z07LZ：LLEG | 26 |
| 992EG $\varepsilon=z$ 90ZIY III！S | $68289 . \varepsilon=z$ ¢6IIY II！S | $0180 \mp 0701$ |  | 96 |
| ธ¢๒G\＆ $\mathcal{E}=z$ 90ZIY III！S |  | 00\％ 0 － $066^{\circ} \mathrm{C}$ | 600干6902\％S | 96 |
|  | $0966{ }^{\circ} \mathrm{E}=z{ }^{\text {o }}$ T | $0780 \mp 0 ¢ \mathrm{C} \cdot \mathrm{S}$ | ［10788890¢ | ロ6 |
|  |  | 080\％ 0 ¢08C\％ |  | $\varepsilon 6$ |
|  |  | $0070 \mp 060$ I | 800干26 $7 ¢ ¢ 9$ | 76 |
|  |  | 098070668 |  | 16 |
| $66289^{\circ} \varepsilon=z 00 Z$ IY IN |  | 07\％ $0 \mp 086 \%$ | 60．0干69 $0^{\circ} \mathrm{tb} 5$ | 06 |
|  |  | 02I $0 \mp 080{ }^{\circ} \mathrm{E}$ | 800\％ 17 Itt | 68 |
|  |  | 0260才080＇9 | IT0干76．98bs | 88 |
|  |  | 0bて， $0 \mp 0780$ |  | 28 |
|  |  | 00\％ 0 ¢029 ${ }^{\circ}$ | I10干 20.86 Ec | 98 |
|  | 80GIS $\mathcal{L}=z^{0} 00 \mathrm{ITY}$ IN | 080\％ 0 ¢16 0 | ［1．0干01．8Its | 98 |
|  | $\angle 62 D D^{\circ} \mathrm{E}=z$ OK T | 092．0干009．L | $60^{\circ} 0 \mp \angle 2 \% 20 b ¢$ | t8 |
|  |  | 01107070 1 | 010718．96E¢ | $\varepsilon 8$ |
|  | $62866^{\circ} \mathrm{E}=z 007 \mathrm{IY}$ IN | 060．0干019＇1 | 9007SS 6685 | 28 |
|  |  | $078^{\cdot 0} 0068 \%$ | 910710．988¢ | 18 |
|  |  | 007．0干099．I | 2007も¢ 7889 | 08 |
|  |  | 07I＇0干088＇I |  | 62 |
|  | $8 \pm 760^{\circ} \mathrm{E}=z$ E6IIY IIIS | 0bI＇07009 ${ }^{(1)}$ |  | 82 |
| G＇I Pq！${ }^{\text {asod }}$ | ио！реэу！${ }^{\text {¢ }}$ | $(\mathrm{V})^{\mathrm{r}} \mathrm{M}$ | ${ }^{\text {sq9 }} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |

（рәnu！̣uoo）：$I \cdot G$ әqeL

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 105 | $5517.62 \pm 0.48$ | $7.850 \pm 4.080$ | Ly $\alpha z=3.53874$ | SiII $\lambda 1193 z=3.62387$ |
| 106 | $5521.82 \pm 0.11$ | $4.030 \pm 0.440$ |  |  |
| 107 | $5527.09 \pm 0.10$ | $3.830 \pm 0.380$ |  |  |
| 108 | $5534.41 \pm 0.16$ | $0.500 \pm 0.080$ | SiIII $\lambda 1206$ | $z=3.58716$ |
| 109 | $5539.45 \pm 0.04$ | $1.870 \pm 0.080$ |  |  |
| 110 | $5545.43 \pm 0.04$ | $1.740 \pm 0.070$ |  |  |
| 111 | $5551.67 \pm 0.05$ | $3.990 \pm 0.130$ |  |  |
| 112 | $5557.96 \pm 0.09$ | $4.950 \pm 0.280$ |  |  |
| 113 | $5561.23 \pm 0.27$ | $2.950 \pm 0.360$ |  |  |
| 114 | $5570.43 \pm 0.11$ | $2.790 \pm 0.260$ |  |  |
| 115 | $5573.32 \pm 0.10$ | $1.250 \pm 0.300$ |  |  |
| 116 | $5576.83 \pm 0.07$ | $4.390 \pm 0.260$ | Ly $\alpha z=3.58745$ |  |
| 117 | $5585.51 \pm 0.10$ | $1.120 \pm 0.110$ |  |  |
| 118 | $5588.55 \pm 0.09$ | $1.280 \pm 0.110$ |  |  |
| 119 | $5601.61 \pm 0.09$ | $1.440 \pm 0.100$ |  |  |
| 120 | $5607.39 \pm 0.04$ | $2.770 \pm 0.080$ |  |  |
| 121 | $5616.60 \pm 0.05$ | $1.890 \pm 0.070$ |  |  |
| 122 | $5621.36 \pm 0.04$ | $1.840 \pm 0.050$ | Ly $\alpha z=3.62408$ |  |
| 123 | $5627.03 \pm 0.08$ | $0.770 \pm 0.050$ |  |  |
|  |  |  |  |  |
| 1 | $3247.36 \pm 0.23$ | $1.240 \pm 0.344$ |  |  |
| 2 | $3249.51 \pm 0.23$ | $0.816 \pm 0.306$ |  |  |
| 3 | $3274.71 \pm 0.12$ | $1.064 \pm 0.187$ |  |  |
| 4 | $3290.72 \pm 0.18$ | $0.886 \pm 0.198$ |  |  |
| 5 | $3316.52 \pm 0.18$ | $1.444 \pm 0.221$ |  |  |
| 6 | $3353.73 \pm 0.11$ | $1.683 \pm 0.200$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 7 | $3376.04 \pm 0.17$ | $1.462 \pm 0.196$ | Ol $\lambda 1302 \quad z=1.59262$ |  |
| 8 | $3384.67 \pm 0.13$ | $0.538 \pm 0.125$ |  |  |
| 9 | $3440.11 \pm 0.08$ | $2.883 \pm 0.164$ |  |  |
| 10 | $3465.59 \pm 0.07$ | $2.211 \pm 0.127$ |  |  |
| 11 | $3479.74 \pm 0.09$ | $0.816 \pm 0.101$ |  |  |
| 12 | $3510.50 \pm 0.08$ | $1.338 \pm 0.108$ |  |  |
| 13 | $3525.59 \pm 0.24$ | $4.662 \pm 0.617$ |  |  |
| 14 | $3528.33 \pm 0.30$ | $0.398 \pm 0.124$ |  |  |
| 15 | $3553.79 \pm 0.07$ | $3.592 \pm 0.160$ | Ly $\alpha=1.92332$ |  |
| 16 | $3560.06 \pm 0.17$ | $1.343 \pm 0.147$ |  |  |
| 17 | $3571.71 \pm 0.05$ | $1.440 \pm 0.138$ |  |  |
| 18 | $3574.84 \pm 0.17$ | $1.424 \pm 0.200$ |  |  |
| 19 | $3581.15 \pm 0.14$ | $0.268 \pm 0.068$ |  |  |
| 20 | $3583.60 \pm 0.17$ | $0.387 \pm 0.080$ |  |  |
| 21 | $3591.98 \pm 0.04$ | $1.706 \pm 0.077$ |  |  |
| 22 | $3636.69 \pm 0.03$ | $1.359 \pm 0.053$ |  |  |
| 23 | $3646.11 \pm 0.06$ | $0.290 \pm 0.040$ |  |  |
| 24 | $3649.75 \pm 0.03$ | $2.140 \pm 0.058$ |  |  |
| 25 | $3660.39 \pm 0.08$ | $0.961 \pm 0.062$ |  |  |
| 26 | $3666.61 \pm 0.09$ | $0.540 \pm 0.052$ |  |  |
| 27 | $3669.93 \pm 0.05$ | $0.850 \pm 0.048$ |  |  |
| 28 | $3684.68 \pm 0.05$ | $0.790 \pm 0.053$ | Sill $\lambda 1260$ | $z=1.92337$ |
| 29 | $3687.30 \pm 0.06$ | $0.853 \pm 0.053$ |  |  |
| 30 | $3691.69 \pm 0.02$ | $1.490 \pm 0.037$ |  |  |
| 31 | $3706.88 \pm 0.03$ | $0.983 \pm 0.032$ |  |  |
| 32 | $3710.40 \pm 0.02$ | $1.169 \pm 0.033$ |  |  |
| 33 | $3807.89 \pm 0.27$ | $0.384 \pm 0.069$ | OI $\lambda 1302$ | $z=1.92427$ |
|  |  |  |  |  |
|  |  |  |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 34 | $3813.45 \pm 0.15$ | $0.241 \pm 0.040$ | SiII $\lambda 1304 z=1.92359$ | CIV $\lambda 1550 z=1.45906$ |
| 35 | $3837.35 \pm 0.07$ | $0.951 \pm 0.053$ |  | CIV $\lambda 1548 z=1.47858$ |
| 36 | $3862.02 \pm 0.30$ | $0.115 \pm 0.189$ |  |  |
| 37 | $3901.41 \pm 0.17$ | $0.870 \pm 0.088$ | CII $\lambda 1334 z=1.92343$ |  |
|  |  |  |  |  |
| 1 | $3251.52 \pm 0.15$ | $1.461 \pm 0.219$ |  |  |
| 2 | $3260.78 \pm 0.24$ | $1.043 \pm 0.207$ |  |  |
| 3 | $3278.19 \pm 0.13$ | $1.038 \pm 0.153$ |  |  |
| 4 | $3293.92 \pm 0.08$ | $1.768 \pm 0.148$ |  |  |
| 5 | $3297.06 \pm 0.09$ | $0.661 \pm 0.112$ | CII $\lambda 1334 z=1.47057$ |  |
| 6 | $3305.57 \pm 0.22$ | $0.809 \pm 0.159$ |  |  |
| 7 | $3321.36 \pm 0.08$ | $0.873 \pm 0.107$ |  |  |
| 8 | $3353.63 \pm 0.09$ | $1.214 \pm 0.140$ | Ly $\alpha z=1.75866$ |  |
| 9 | $3356.82 \pm 0.09$ | $1.085 \pm 0.121$ |  |  |
| 10 | $3359.92 \pm 0.09$ | $1.061 \pm 0.116$ |  | SiII $\lambda 1193 z=1.87557$ |
| 11 | $3392.17 \pm 0.15$ | $0.968 \pm 0.134$ |  |  |
| 12 | $3400.73 \pm 0.33$ | $0.731 \pm 0.162$ |  |  |
| 13 | $3419.79 \pm 0.18$ | $0.955 \pm 0.131$ |  |  |
| 14 | $3431.40 \pm 0.09$ | $0.713 \pm 0.079$ |  |  |
| 15 | $3449.02 \pm 0.08$ | $0.824 \pm 0.074$ | NI $\lambda 1200 z=1.87418$ |  |
| 16 | $3464.84 \pm 0.04$ | $0.882 \pm 0.071$ |  |  |
| 17 | $3466.88 \pm 0.04$ | $1.330 \pm 0.077$ |  | SiIII $\lambda 1206 z=1.89643$ |
| 18 | $3475.82 \pm 0.07$ | $0.246 \pm 0.044$ | NI $\lambda 1200 z=1.89651$ | SiII $\lambda 1260 z=1.75766$ |
| 19 | $3485.92 \pm 0.09$ | $0.259 \pm 0.056$ |  |  |
| 20 | $3494.55 \pm 0.03$ | $2.059 \pm 0.061$ | Ly $\alpha z=1.87458$ |  |
| 21 | $3502.17 \pm 0.06$ | $1.133 \pm 0.070$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 22 | $3505.18 \pm 0.03$ | $1.640 \pm 0.078$ |  |  |
| 23 | $3508.27 \pm 0.24$ | $0.422 \pm 0.090$ |  |  |
| 24 | $3512.55 \pm 0.10$ | $0.883 \pm 0.079$ | CII $\lambda 1334 z=1.63205$ |  |
| 25 | $3520.97 \pm 0.04$ | $1.398 \pm 0.059$ | Ly $\alpha z=1.89632$ |  |
| 26 | $3524.75 \pm 0.12$ | $0.423 \pm 0.060$ |  |  |
| 27 | $3530.00 \pm 0.15$ | $0.080 \pm 0.023$ |  |  |
| 28 | $3541.60 \pm 0.09$ | $0.466 \pm 0.051$ |  |  |
| 29 | $3547.39 \pm 0.05$ | $1.359 \pm 0.059$ |  |  |
| 30 | $3550.67 \pm 0.03$ | $0.872 \pm 0.045$ |  |  |
| 31 | $3555.06 \pm 0.21$ | $0.301 \pm 0.053$ |  |  |
| 32 | $3559.53 \pm 0.16$ | $0.164 \pm 0.037$ |  |  |
| 33 | $3566.33 \pm 0.04$ | $0.676 \pm 0.041$ |  |  |
| 34 | $3624.73 \pm 0.07$ | $0.409 \pm 0.039$ | CIV $\lambda 1548$ | $z=1.34125$ |
| SiII $\lambda 1260$ | $z=1.87580$ |  |  |  |
| 35 | $3631.19 \pm 0.07$ | $0.207 \pm 0.031$ | CIV $\lambda 1550 z=1.34153$ |  |
| 36 | $3657.51 \pm 0.07$ | $0.175 \pm 0.030$ |  |  |
| 37 | $3669.02 \pm 0.23$ | $0.407 \pm 0.066$ | SiIV $\lambda 1393 z=1.63247$ |  |
| 38 | $3692.00 \pm 0.25$ | $0.336 \pm 0.065$ | SilV $\lambda 1402 z=1.63194$ |  |
| 39 | $3771.95 \pm 0.02$ | $0.907 \pm 0.038$ | OI $\lambda 1302 z=1.89666$ | SiII $\lambda 1526 z=1.47064$ |
| 40 | $3787.07 \pm 0.04$ | $0.384 \pm 0.034$ |  |  |
| 41 | $3790.07 \pm 0.11$ | $0.204 \pm 0.038$ |  |  |
| 42 | $3829.06 \pm 0.18$ | $0.226 \pm 0.060$ |  | MgI $\lambda 2853 z=0.36768$ |
| 43 | $3830.90 \pm 0.17$ | $0.209 \pm 0.058$ |  |  |
| 44 | $3901.97 \pm 0.08$ | $0.141 \pm 0.029$ |  | CalI $\lambda 3935 z=-0.0002$ |
| 45 | $3904.19 \pm 0.07$ | $0.311 \pm 0.035$ |  |  |
| 46 | $3911.16 \pm 0.01$ | $0.509 \pm 0.026$ | AlII $\lambda 1670 z=1.34090$ |  |
| 47 | $3933.57 \pm 0.31$ | $0.384 \pm 0.074$ |  |  |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| Q 2134+004 |  |  |  |  |
| 1 | $3317.39 \pm 0.20$ | $1.341 \pm 0.276$ |  |  |
| 2 | $3341.63 \pm 0.13$ | $1.020 \pm 0.196$ |  |  |
| 3 | $3366.26 \pm 0.15$ | $0.861 \pm 0.192$ |  |  |
| 4 | $3404.83 \pm 0.14$ | $0.664 \pm 0.160$ |  |  |
| 5 | $3433.21 \pm 0.09$ | $0.472 \pm 0.115$ |  |  |
| 6 | $3436.70 \pm 0.10$ | $1.980 \pm 0.192$ |  |  |
| 7 | $3448.91 \pm 0.09$ | $1.633 \pm 0.187$ |  |  |
| 8 | $3451.55 \pm 0.13$ | $1.291 \pm 0.198$ |  |  |
| 9 | $3474.87 \pm 0.06$ | $1.737 \pm 0.138$ |  |  |
| 10 | $3478.89 \pm 0.15$ | $1.272 \pm 0.187$ |  |  |
| 11 | $3489.09 \pm 0.28$ | $0.892 \pm 0.234$ |  |  |
| 12 | $3492.73 \pm 0.07$ | $1.316 \pm 0.133$ |  |  |
| 13 | $3508.12 \pm 0.15$ | $0.620 \pm 0.117$ |  |  |
| 14 | $3548.85 \pm 0.13$ | $0.830 \pm 0.098$ |  |  |
| 15 | $3559.86 \pm 0.11$ | $0.510 \pm 0.066$ |  |  |
| 16 | $3588.44 \pm 0.03$ | $1.222 \pm 0.052$ |  |  |
| 17 | $3818.07 \pm 0.15$ | $0.511 \pm 0.101$ |  | MgII $\lambda 2796 z=0.36547$ |
| 18 | $3881.03 \pm 0.12$ | $0.754 \pm 0.103$ |  |  |
| 19 | $3935.29 \pm 0.23$ | $0.428 \pm 0.102$ |  |  |
| Q 2251+244 |  |  |  |  |
| 1 | $3416.24 \pm 0.16$ | $1.902 \pm 0.342$ |  | NV $\lambda 1242 z=1.74881$ |
| 2 | $3437.98 \pm 0.41$ | $1.332 \pm 2.164$ | $\mathrm{Ly} \beta z=2.35176$ |  |
| 3 | $3440.64 \pm 1.71$ | $2.521 \pm 2.615$ |  | OVI $\lambda 1037 z=2.31591$ |
| 4 | $3450.48 \pm 0.13$ | $4.025 \pm 0.400$ | Ly $\beta z=2.36395$ | SiII $\lambda 1190 z=1.89854$ |
| 5 | $3459.00 \pm 0.18$ | $2.321 \pm 0.356$ | OVI $\lambda 1031 z=2.35198$ | Sill $\lambda 1193 z=1.89871$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $W_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 6 | $3470.24 \pm 0.16$ | $0.998 \pm 0.895$ | OVI $\lambda 1031 z=2.36287$ | NI $\lambda 1135 z=2.05753$ |
| 7 | $3472.32 \pm 0.52$ | $3.838 \pm 1.335$ |  |  |
| 8 | $3478.56 \pm 0.23$ | $3.071 \pm 0.487$ | OVI $\lambda 1037 z=2.35245$ | NI $\lambda 1200 z=1.89880$ |
| 9 | $3490.54 \pm 0.19$ | $3.594 \pm 0.460$ | OVI $\lambda 1037 z=2.36400$ | AIII $\lambda 1670 z=1.08915$ |
| 10 | $3524.64 \pm 0.29$ | $2.331 \pm 0.428$ | Ly $~$ | $z=1.89880$ |
| 11 | $3532.41 \pm 0.13$ | $1.669 \pm 0.245$ |  |  |
| 12 | $3553.81 \pm 0.35$ | $1.004 \pm 0.319$ |  |  |
| 13 | $3617.37 \pm 0.11$ | $1.685 \pm 0.222$ |  |  |
| 14 | $3619.75 \pm 0.09$ | $0.652 \pm 0.151$ |  |  |
| 15 | $3627.15 \pm 0.17$ | $0.744 \pm 0.201$ |  |  |
| 16 | $3635.98 \pm 0.19$ | $2.337 \pm 0.327$ |  |  |
| 17 | $3642.98 \pm 0.18$ | $1.379 \pm 0.232$ |  |  |
| 18 | $3649.95 \pm 0.25$ | $1.071 \pm 0.257$ |  |  |
| 19 | $3652.96 \pm 0.34$ | $1.238 \pm 0.390$ | SiII $\lambda 1260 z=1.89820$ |  |
| 20 | $3657.03 \pm 0.20$ | $1.182 \pm 0.266$ |  |  |
| 21 | $3660.25 \pm 0.26$ | $1.157 \pm 0.283$ | SiIII $\lambda 1206 z=2.03378$ |  |
| 22 | $3664.54 \pm 0.29$ | $0.742 \pm 0.221$ |  |  |
| 23 | $3667.90 \pm 0.16$ | $0.676 \pm 0.171$ | NI $\lambda 1200 z=2.05658$ |  |
| 24 | $3671.73 \pm 0.11$ | $2.794 \pm 0.247$ |  |  |
| 25 | $3684.01 \pm 0.08$ | $1.734 \pm 0.198$ |  |  |
| 26 | $3687.88 \pm 0.19$ | $2.415 \pm 0.309$ | Ly $\alpha z=2.03362$ | SiIII $\lambda 1206 z=2.05668$ |
| 27 | $3716.28 \pm 0.08$ | $2.134 \pm 0.174$ | Ly $\alpha z=2.05698$ |  |
| 28 | $3745.73 \pm 0.21$ | $1.520 \pm 0.221$ | SiIII $\lambda 1206 z=2.10462$ |  |
| 29 | $3765.58 \pm 0.40$ | $1.227 \pm 0.282$ | SiII $\lambda 1193 z=2.15563$ |  |
| 30 | $3774.95 \pm 0.10$ | $1.858 \pm 0.173$ | Ly $\alpha z=2.10524$ | OI $\lambda 1302 z=1.89897$ |
| 31 | $3782.72 \pm 0.23$ | $1.494 \pm 0.292$ |  |  |
| 32 | $3786.39 \pm 0.17$ | $2.052 \pm 0.288$ | NV $\lambda 1238 z=2.05645$ | NI $\lambda 1200 z=2.15532$ |

Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 33 | $3798.66 \pm 0.22$ | $1.455 \pm 0.222$ | NV $\lambda 1242 z=2.05652$ |  |
| 34 | $3807.84 \pm 0.12$ | $1.392 \pm 0.180$ |  | SiIII $\lambda 1206 z=2.15610$ |
| 35 | $3811.65 \pm 0.23$ | $1.180 \pm 0.233$ |  | SiII $\lambda 1260 \quad z=2.03251$ |
| 36 | $3822.24 \pm 0.23$ | $0.927 \pm 0.187$ |  |  |
| 37 | $3828.85 \pm 0.12$ | $1.014 \pm 0.153$ |  | FeII $\lambda 1145 z=2.35235$ |
| 38 | $3835.42 \pm 0.28$ | $1.887 \pm 1.010$ | Ly $\alpha z=2.15498$ |  |
| 39 | $3838.21 \pm 0.39$ | $4.419 \pm 1.122$ |  |  |
| 40 | $3862.39 \pm 0.18$ | $0.595 \pm 0.151$ |  |  |
| 41 | $3885.84 \pm 0.11$ | $3.739 \pm 0.262$ |  |  |
| 42 | $3890.76 \pm 0.27$ | $1.053 \pm 0.209$ |  |  |
| 43 | $3906.20 \pm 0.97$ | $2.226 \pm 0.701$ |  |  |
| 44 | $3909.42 \pm 0.14$ | $0.578 \pm 0.236$ |  |  |
| 45 | $3913.58 \pm 0.32$ | $0.844 \pm 0.189$ | Sill $\lambda 1260 \quad z=2.10497$ |  |
| 46 | $3921.91 \pm 0.14$ | $0.993 \pm 0.131$ |  |  |
| 47 | $3926.10 \pm 0.11$ | $1.133 \pm 0.125$ |  |  |
| 48 | $3931.11 \pm 0.11$ | $1.268 \pm 0.127$ | MgII $\lambda 2796 z=0.40580$ |  |
| 49 | $3934.73 \pm 0.29$ | $0.617 \pm 0.325$ |  |  |
| 50 | $3937.19 \pm 0.39$ | $0.954 \pm 0.440$ |  |  |
| 51 | $3940.37 \pm 0.33$ | $0.492 \pm 0.220$ |  |  |
| 52 | $3943.91 \pm 0.22$ | $0.648 \pm 0.144$ |  |  |
| 53 | $3949.42 \pm 0.26$ | $0.982 \pm 0.175$ | OI $\lambda 1302 z=2.03296$ |  |
| 54 | $3958.71 \pm 0.17$ | $3.028 \pm 0.391$ |  |  |
| 55 | $3962.43 \pm 0.14$ | $3.061 \pm 0.361$ |  |  |
| 56 | $3976.43 \pm 0.10$ | $0.766 \pm 0.323$ | SiII $\lambda 1260 z=2.15484$ |  |
| 57 | $3979.14 \pm 0.49$ | $1.514 \pm 0.470$ | NI $\lambda 1200 z=2.13595$ | SiIII $\lambda 1206 z=2.29809$ |
| 58 | $3986.13 \pm 0.11$ | $1.758 \pm 0.150$ |  |  |
| 59 | $3989.53 \pm 0.15$ | $0.456 \pm 0.107$ |  |  |


|  |  | 627．07079 ${ }^{\circ}$ |  | $\varepsilon 1$ |
| :---: | :---: | :---: | :---: | :---: |
|  |  | 98507 0 29\％ |  | ZI |
|  |  |  | \＆ $8^{\circ} 0 \mp \angle 9^{\circ} 0298$ | II |
|  |  | $8 \mathrm{bz} 0 \mp 600 \mathrm{I}$ | cz：0于900998 | 0I |
|  |  | 8IE0干EIでI | 0で0干7L．9998 | 6 |
|  |  | $92 \varepsilon^{\circ} 0 \mp \varepsilon\left[\varepsilon^{\prime} \mathrm{I}\right.$ | 1 $10 \mp 9 \pm$ ¢ 998 | 8 |
|  |  | 978．0于88\％\％ | \＆1．0干18．8598 | 2 |
|  |  | ZLE $0 \mp 818^{\circ} \mathrm{L}$ | $18.0 \mp 297898$ | 9 |
|  |  | 81も0才IL9 ${ }^{\text {I }}$ |  | g |
|  |  | －¢9 $1 \mp ¢ 870$ ¢ | $60^{\circ} \mathrm{T} 719{ }^{\circ} \mathrm{L} 98$ | $\nabla$ |
|  |  | $6180 \mp 16{ }^{\circ} \mathrm{T}$ | L2＇07 28.2098 | $\varepsilon$ |
|  |  | EE\＆＇I干下LI＇\％ | 90．0786 7698 | $\zeta$ |
|  |  |  |  | I |
|  |  |  |  |  |
|  |  | L\＆¢07067．9 | $60.0 \mp 98.2800$ | IL |
|  | ¢9198．z＝z 0К＇ | 6II $0 \mp 886{ }^{\circ}$ | 90.0 于67＊ 206 | 02 |
|  |  | $668^{\circ} 0 \mp 066.0$ | 69．0788 ${ }^{\circ} \mathrm{8c} 0^{\circ}$ | 69 |
|  |  | L60．0干9990 | 810干98．090\％ | 89 |
|  |  | $6600 \mp 9190$ | crofal ciot | $\angle 9$ |
|  |  | \＆II＇0才9L60 | ［1．0781．280ヵ | 99 |
|  |  |  | ع10干06．0¢0¢ | ¢9 |
|  |  | 8Z1．0〒768＇I | $60.0 \mp 9 L^{\circ} 810$ b | ¢9 |
|  |  | 881．0 $0806{ }^{\circ} \mathrm{L}$ | If07tcolot | ¢9 |
|  |  |  | \＆1．0干78．900¢ | 79 |
|  | 889EI＇Z＝z 907TY IIIIS | İI＇0才001＇L | $81^{\circ} 0 \mp 1 Z^{\prime} 100{ }^{\text {c }}$ | I9 |
|  |  | 6II＇0才02L：0 | 81．07¢ ${ }^{\circ} 9668$ | 09 |
| ＇G＇I Plq！ssod | иопреэу！${ }^{\text {a }}$ | （y）${ }^{\gamma} M$ | ${ }^{\text {89\％}} \mathrm{Y}$ | ${ }^{\circ} \mathrm{N}$ |



Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 14 | $3696.53 \pm 0.11$ | $0.586 \pm 0.118$ |  |  |
| 15 | $3707.97 \pm 0.10$ | $1.809 \pm 0.150$ |  |  |
| 16 | $3717.35 \pm 0.06$ | $2.497 \pm 0.125$ |  |  |
| 17 | $3727.74 \pm 0.28$ | $1.506 \pm 0.323$ |  |  |
| 18 | $3731.67 \pm 0.48$ | $0.515 \pm 0.258$ |  |  |
| 19 | $3735.52 \pm 0.10$ | $1.336 \pm 0.113$ |  |  |
| 20 | $3740.93 \pm 0.10$ | $0.534 \pm 0.067$ |  |  |
| 21 | $3745.27 \pm 0.06$ | $1.084 \pm 0.065$ |  |  |
| 22 | $3808.18 \pm 0.08$ | $0.918 \pm 0.109$ |  |  |
| 23 | $3823.07 \pm 0.10$ | $0.376 \pm 0.087$ |  |  |
| 24 | $3831.99 \pm 0.15$ | $0.440 \pm 0.097$ |  |  |
|  |  |  |  |  |
| 25 | $3836.63 \pm 0.18$ | $0.816 \pm 0.133$ |  |  |
|  |  |  | QiV $\lambda 1402$ | $z=1.73173$ |
| 1 | $3604.38 \pm 0.27$ | $2.969 \pm 0.722$ |  | $z=1.47512$ |
| 2 | $3692.60 \pm 0.07$ | $1.274 \pm 0.252$ |  |  |
| 3 | $3742.69 \pm 0.13$ | $1.540 \pm 0.310$ |  |  |
| 4 | $3789.80 \pm 0.16$ | $3.330 \pm 0.440$ |  |  |
| 5 | $3793.86 \pm 0.09$ | $1.120 \pm 0.220$ |  |  |
| 6 | $3799.16 \pm 0.17$ | $1.160 \pm 0.400$ |  |  |
| 7 | $3801.83 \pm 0.33$ | $1.770 \pm 0.530$ |  |  |
| 8 | $3812.04 \pm 0.14$ | $1.560 \pm 0.250$ |  |  |
| 9 | $3831.80 \pm 0.14$ | $3.140 \pm 0.360$ |  |  |
| 10 | $3852.62 \pm 0.24$ | $0.700 \pm 0.160$ |  |  |
| 11 | $3866.67 \pm 0.21$ | $0.700 \pm 0.140$ |  |  |
| 12 | $3870.30 \pm 0.12$ | $1.120 \pm 0.140$ | MgII $\lambda 2796$ | $z=0.38405$ |

Table B.1: (continued)


Table B.1: (continued)

| No. | $\lambda_{\text {obs }}$ | $\mathrm{W}_{\lambda}(\AA)$ | Identification | Possible I.D. |
| :---: | :---: | :---: | :---: | :---: |
| 5 | $3513.14 \pm 0.04$ | $1.737 \pm 0.092$ |  |  |
| 6 | $3520.85 \pm 0.05$ | $2.054 \pm 0.112$ |  |  |
| 7 | $3530.61 \pm 0.13$ | $0.521 \pm 0.093$ |  |  |
| 8 | $3545.63 \pm 0.08$ | $1.136 \pm 0.125$ | CIV $\lambda 1548 z=1.29015$ |  |
| 9 | $3548.72 \pm 0.08$ | $1.378 \pm 0.158$ | CIV $\lambda 1548$ | $z=1.29215$ |
| 10 | $3551.43 \pm 0.13$ | $1.222 \pm 0.189$ | CIV $\lambda 1550 z=1.29010$ |  |
| 11 | $3554.57 \pm 0.11$ | $1.453 \pm 0.188$ | CIV $\lambda 1550 z=1.29212$ |  |
| 12 | $3561.22 \pm 0.87$ | $1.348 \pm 0.733$ |  |  |
| 13 | $3613.33 \pm 0.10$ | $2.163 \pm 0.185$ | CIV $\lambda 1548 z=1.33388$ |  |
| 14 | $3619.21 \pm 0.11$ | $2.260 \pm 0.208$ | CIV $\lambda 1550 z=1.33380$ |  |
| 15 | $3784.10 \pm 0.08$ | $0.676 \pm 0.119$ |  |  |
| 16 | $3786.23 \pm 0.07$ | $0.625 \pm 0.111$ |  |  |
| 17 | $3839.38 \pm 0.27$ | $0.713 \pm 0.186$ |  |  |

## Appendix C Notes on Individual MMT Objects

## C. 1 Q 0006+020 <br> $$
z_{e m}=2.340
$$

This QSO was identified by (87) Foltz et al. (1989). (265) Tytler et al. (1993), hereafter T93, discuss the redshift systems they find in their red ( $4312 \AA-7059 \AA$ ), low resolution ( $8.6 \AA$ FWHM) spectrum of this object. We do not confirm the first system they find at $z_{a b s}=1.131$. This identification was based on the detection of Mg II $\lambda \lambda 2796,2803$ at $5960 \AA$ and $5975 \AA$ respectively which we do not detect in our red spectrum of this object, which is presented in Paper II of this series. The second system (265) T93 find is at $z_{a b s}=2.034$ for which they identify the C IV doublet at $4700 \AA$ and $\mathrm{Al} \mathrm{II} \lambda 1670$ at $5073 \AA$. The positions of Ly $\alpha$ and Si III $\lambda 1206$ for this redshift lie on bad columns in the data, but we identify N II $\lambda 1083$ at $3289 \AA$, a possible N V doublet at $3757 \AA$ and $3770 \AA$, Si II $\lambda 1260$ at $3825 \AA$, and C II $\lambda 1334$ at $4050 \AA$. In addition, our red spectrum of this QSO confirms the C IV doublet and Al II identifications of T93 while also revealing the Si IV doublet at $4227 \AA$ and $4252 \AA$ and a possible Si II $\lambda 1526$ line at $4632 \AA$. Identifying the $4700 \AA$ line in the spectrum of (265) T93 as Si IV $\lambda 1393$ reveals the third system, at $z_{a b s}=2.374$. We identify Ly $\beta$ at $3460 \AA$, O VI $\lambda 1031$ and $\lambda 1037$ at $3482 \AA$ and $3501 \AA$, and N I $\lambda 1200$ at $4050 \AA$. Our red data confirm the $4700 \AA$ feature as well as the C IV doublet at $\sim 5222 \AA$ for this redshift. This system is consistent with an associated absorber as proposed by (87) Foltz et al. (1989).

We also detect several other systems using the methods and criteria described above:
$z_{\mathrm{abs}}=1.6094-$ This is a system showing Si II $\lambda 1260$ at $3289 \hat{A}, \mathrm{C}$ II $\lambda 1334$ at $3482 \AA$, Si IV $\lambda 1393$ at $3637 \AA$ (the position of the $\lambda 1402$ component lies on a bad
column but there is an absorption feature at this wavelength in our red spectrum), and Si II $\lambda 1526$ at $3984 \AA$ (which is blended with Ly $\alpha$ at $z_{a b s}=2.2775$.) In addition, our red spectrum (see Paper II) shows a line at $4362 \AA$, consistent with Al II $\lambda 1670$ for this redshift.
$z_{a b s}=1.8189-$ At this redshift, we identify Ly $\alpha$ at $3427 \AA, N$ I $\lambda 1200$ at $3383 \AA$, a tentative $N$ V doublet at $3491 \AA$ and $3501 \AA$ (where the $\lambda 1242$ component must be blended with Ly $\alpha$ at $z_{a b s}=1.880$ and/or O VI $\lambda 1037$ at $z_{a b s}=2.375$ ), and C II $\lambda 1334$ at $3762 \AA$. The C IV doublet at this redshift is visible in our red spectrum at a wavelength of $4367 \AA$.
$z_{a b s}=1.8409$ - For this system, we detect Ly $\alpha 3454 \AA$, Si III $\lambda 1206$ at $3427 \AA, \mathrm{Si}$ II $\lambda 1260$ at $3579 \AA$, and C II $\lambda 1334$ at $3791 \AA$. Our red spectrum does not show any lines redward of Ly $\alpha$ consistent with this redshift.
$z_{a b s}=1.8802$ - This system is composed of Ly $\alpha$ at $3501 \AA$, a N V doublet at $3568 \AA$ and $3579 \AA$, C II $\lambda 1334$ at $3845 \AA$, and a possible weak Si IV $\lambda 1393$ line at $4015 \AA$ (no $\lambda 1402$ is detected.) No lines redward of Ly $\alpha$ are detected in the red spectrum.
$z_{a b s}=2.2775$ - This is a system showing Ly $\alpha$ at $3984 \AA, \operatorname{Ly} \beta$ at $3363 \AA$, Si III $\lambda 1206$ at $3955 \AA$, and the N V doublet at $4060 \AA$ and $4072 \AA$. (The position of Fe II $\lambda 1145$ falls on a bad column for this redshift.) A possible C IV doublet identification is made from the red spectrum at $5076 \AA$.

Lastly, we find a possible Mg II absorber at $z_{a b s}=0.448$. However, the implied Fe II lines are not consistent with line ratios. Therefore, since only two lines are found, this system cannot qualify as a metal line system by our criteria.

## C. 2 Q 0027+014 <br> $$
z_{e m}=2.310
$$

(241) Steidel \& Sargent (1992), hereafter SS92, find a single Mg II system for this object at $z_{a b s}=1.2664$ using their red setup ( $5128-8947 \AA$ ) with 4-6 $\AA$ resolution. In addition to Mg II $\lambda \lambda 2796,2803$ (at $6336 \AA$ and $6352 \AA$ respectively), they identify Fe

II $\lambda 2382$ at $5400 \AA$. We confirm this system with our detection of the C IV doublet at $3508 \AA$ and $3513 \AA$ as well as Al II $\lambda 1670$ at $3786 \AA$. Our red spectrum of this object (see Paper II) shows the Fe II line found by SS92, but shows only marginal evidence for the Mg II doublet.

We also identify two other redshift systems in our spectrum:
$z_{a b s}=1.8415-$ We find Ly $\alpha$ at $3454 \AA$, N I $\lambda 1200$ at $3411 \AA$, Si III $\lambda 1206$ at $3428 \AA$, Si II $\lambda 1260$ at $3582 \AA$, a possible, blended C II $\lambda 1334$ line $3793 \AA$, and the Si IV doublet at $3960 \AA$ and $3986 \AA$. However, the doublet ratio for the Si IV doublet is greater than two; therefore, the $\lambda 1393$ component must be blended. Our red spectrum shows Si II $\lambda 1526$ at $4337 \AA$, the C IV doublet at $4403 \AA$, Fe II $\lambda 1608$ at $4572 \AA$, and Al II $\lambda 1670$ at $4748 \AA$.
$z_{a b s}=1.9859-\operatorname{Ly} \alpha$ for this possible system is found at $3630 \AA$. At this redshift, we also identify N II $\lambda 1083$, Fe II $\lambda 1145$, Si II $\lambda 1193$ and $\lambda 1260$ lines at $3237 \AA, 3419 \AA$, $3563 \AA$, and $3763 \AA$. The equivalent widths relative to Ly $\alpha$ indicate each of these must be blended. A Si III $\lambda 1206$ line is found at $3603 \AA$. The red spectrum shows no lines for this redshift redward of $\mathrm{Ly} \alpha$.

## C. 3 Q 0037-018 $\quad z_{\text {em }}=2.341$

(284) Wolfe et al. (1986), hereafter W86, find a candidate damped Ly $\alpha$ system present in the spectrum of this object at $3602 \AA\left(z_{a b s}=1.962\right)$ with an observed equivalent width of $15.5 \AA$. They also note an absorption feature at $3832 \AA\left(z_{a b s}=2.152\right)$. However, since their objective was to search for and characterize damped Ly $\alpha$ systems only, they do not produce detailed line lists for their spectra. These lines are not confirmed by our data. We find no significant absorption feature at $3602 \mathcal{A}$; but we do find a line at 3604 A. We also find no significant line at 3832 A. Due to the low signal-to-noise at the blue end of our spectrum, we truncated the spectrum for the purposes of our line searches. The usable portion of our spectrum therefore extends
from $\sim 3542 \AA$ to $\sim 4110 \AA$. The features at $3998 \AA, 4003 \AA, 4007 \AA$, and $4011 \AA$ are identified as traps in the CCD, as they appear in many other object spectra.

## C. 4 Q 0049+007 $\quad z_{e m}=2.279$

We find a system consistent with Ly $\alpha$ at $3540 \AA$. (241) SS92 (cf. Section C.2) identify this metal line system at $z_{\text {abs }}=1.9115$ on the basis of weak Al III $\lambda 1854$ and $\lambda 1862$ lines and a weak Mg II doublet. Further corroboration of this system comes from a possible N V $\lambda 1238$ line at $3607 \AA$ (no $\lambda 1242$ is detected) and the Si IV doublet at $4057 \AA$ and $4084 \AA$ respectively in our data. Our red spectrum of this object (see Paper II) also shows Si II $\lambda 1526$ at $4445 \AA$, and the C IV doublet at $4507 \AA$ and $4515 \AA$, consistent with this system.

In addition, we find five other systems or possible systems from our data:
$z_{a b s}=1.3865-$ We identify this system based on the C IV doublet at $3695 \AA$ and $3701 \AA$. We also find Si II $\lambda 1526$ at $3643 \AA$, and Al II $\lambda 1670$ at $3987 \AA$. (241) SS92 do not find a Mg II doublet nor do they find any Fe II lines at this redshift. Our red spectrum shows possible Al III $\lambda 1854$ and $\lambda 1862$ lines at $4426 \AA$ and $4445 \AA$. However, the feature at $4445 \AA$ is more likely Si IV $\lambda 1393$ at $z_{a b s}=2.1908$.
$z_{\mathrm{abs}}=1.5226-$ This system is composed of O I $\lambda 1302$ at $3285 \AA$, Si IV $\lambda 1393$ at $3515 \AA$ and $\lambda 1402$ at $3540 \AA$ (blended with Ly $\alpha$ at $z_{a b s}=1.9123$ ), a possible identification of Si II $\lambda 1526$ at $3850 \AA$, and the C IV doublet at $3905 \AA$ and $3912 \AA$. (241) SS92 do not detect a Mg II doublet or any Fe II lines at this redshift, nor do we find any matching lines in our red spectrum.
$z_{a b s}=2.1168$ - This is a relatively insecure identification based upon Ly $\alpha$ at $3789 \AA$, a possible O I $\lambda 1302$ at $4057 \AA$ and possible Si II $\lambda 1193$ and $\lambda 1260$ lines at $3720 \AA$ and $3927 \AA$. No lines are found redward of Ly $\alpha$ emission.
$z_{a b s}=2.1667$ - This system shows $\operatorname{Ly} \alpha$ at $3850 \hat{A}, \operatorname{Ly} \beta$ at $3248 \hat{A}$, and a very tentative N V doublet both components of which must be blends at $3927 \AA$ and
$3935 \AA$. We find no lines at this redshift in our red spectrum
$z_{a b s}=2.1918$ - For this system, we find Ly $\alpha$ at $3880 \AA, \operatorname{Ly} \beta$ at $3274 \AA, \mathrm{Si}$ III $\lambda 1206$ at $3850 \AA$, and a possible, blended N II $\lambda 1083$ at $3458 \AA$. In addition, our red spectrum shows the Si IV doublet at $4447 \AA$ and $4476 \AA$ and the C IV doublet at $4944 \AA$.

## C. $5 \quad$ Q $0123+257 \quad z_{\text {em }}=2.370$

The absorption spectrum of this QSO has been observed by (218) Schmidt \& Olsen (1968) (SO68), (188) Oemler \& Lynds (1975) (OL75), and (284) W86 (cf. Section C.3).

We confirm the absorption features seen by (218) SO68 at $3900 \AA, 4013 \AA, 4057 \AA$, and $4065 \AA$. The remainder of their features lie outside the wavelength range of our spectrum. They report an absorption system at $z_{a b s}=2.3683$, an associated absorber, from the identification of Ly $\alpha$ and the C IV doublet, as well as a possible identification of Si III $\lambda 1206$. (188) OL75 discuss several possible redshift systems. The only system they find compelling, however, is the $z_{a b s}=2.3683$ system of (218) SO68. We confirm several lines possibly associated with this system: Ly $\beta$ at $3456 A$, O VI $\lambda \lambda 1031,1037$ at $3473 \AA$ and $3496 \AA, N$ II $\lambda 1083$ at $3645 \AA$, and Si III $\lambda 1206$ at $4064 \AA$ which is blended with Ly $\alpha$ at $z_{a b s}=2.3433$. Our red spectrum of this object (see Paper II) shows the C IV doublet at $5216 \AA$ and $5226 \AA$. We also confirm the absence of any marked damped Ly $\alpha$ absorption, as reported by (284) W86.

We tested all of the possible redshift systems proposed by (188) OL75 and used our usual methods for finding additional metal line systems. As a result, we identify three other systems:
$z_{a b s}=0.3207$ - This system consists of Fe II $\lambda 2600$ at $3433 \AA$, a Mg II doublet at $3693 \AA$ and $3702 \AA$, and Mg I $\lambda 2753$ at $3767 \AA$.
$z_{a b s}=1.8427$ - This system consists of Ly $\alpha$ at $3456 \AA$, Si III $\lambda 1206$ at $3430 \AA$, O I
$\lambda 1302$ at $3702 \AA$, and Si IV $\lambda 1393$ at $3962 \AA$, with a possible identification of $\lambda 1402$ blended with a feature at $3989 \AA$.
$z_{a b s}=2.0379-$ For this system, we find Ly $\alpha$ at $3693 \AA$, Fe II $\lambda 1143$ and a blended $\lambda 1145$ at $3473 \AA$ and $3478 \AA$, and N I $\lambda 1200$ at $3645 \AA$. Neither (218) SO68 nor (188) OL75 note any absorption features at the position of Fe II $\lambda 1608$ for this redshift; and our red spectrum shows no lines at this redshift.

## C. 6 Q 0150-203 $\quad z_{e m}=2.148$

The absorption spectrum of 0150-203 (UM675) is first discussed in detail by (212) Sargent et al. (1988), hereafter SBS88. Their data provide coverage from $3815 \AA$ to $5038 \AA$ with $1.5 \AA$ resolution. They report several absorption systems from their spectrum:
$z_{a b s}=0.3892-\mathrm{A} \mathrm{Mg}$ II doublet is identified at this redshift. (212) SBS88 report the possible blending of the Mg II doublet at $z_{a b s}=0.3892$ with a second component at $z_{a b s}=0.3882$. Our spectrum does show two prominent absorption features at 3883 and $3896 \AA$. If these lines are interpreted as the Mg II doublet the resulting redshifts are $z_{a b s}=0.38869$ for the $\lambda 2796$ line and $z_{a b s}=0.38977$ for the $\lambda 2803$ line, an unacceptable separation of $233 \mathrm{~km} \mathrm{~s}^{-1}$. It is possible to identify three Fe II lines at this redshift, $\lambda 2344$ at $3253 \AA, \lambda 2382$ at $3308 \AA$, and $\lambda 2586$ at $3590 \AA$. However, no Fe II $\lambda 2600$ line is found which calls the identification of the $\lambda 2344$ and the $\lambda 2586$ lines into question. Given these arguments and the more compelling identification of the $3883 \AA$ and $3896 \AA$ features as the N V doublet at $z_{a b s}=2.134$, we consider this system improbable.
$z_{a b s}=0.7800-\mathrm{A}$ Mg II system showing Fe II $\lambda 2382$ is reported by (212) SBS88. The only lines in our search list that fall within the wavelength range of our data for $z_{a b s}=0.7800$ are Al III $\lambda 1854$ and $\lambda 1862$, but we detect neither of these, and thus cannot confirm this system.
$z_{a b s}=1.7666-(212)$ SBS88 detect a weak C IV doublet at this redshift. We confirm this system from our detection of Ly $\alpha$ at $3363 \AA$ and possible identifications of O I $\lambda 1302$ at $3604 \AA$, and C II $\lambda 1334$ at $3693 \AA$.
$z_{a b s}=1.9287-(212)$ SBS88 regard this weak C IV doublet as a probable system. We confirm this system through our identifications of Ly $\alpha$ at $3560 \AA$ and tentative Si II $\lambda 1193, \lambda 1260$, and $\lambda 1304$ lines at $3494 \AA, 3690 \AA$ and $3821 \AA$ respectively.
$z_{a b s}=2.0083,2.0097-(212)$ SBS88 regard this C IV complex as almost certain due to the good redshift agreement between the putative doublet lines. The Si IV $\lambda 1393$ line is also identified for the $z_{a b s}=2.0097$ component of this complex. We confirm the $z_{a b s}=2.0083$ system. At this redshift, we identify lines of Ly $\alpha$ at $3657 \AA, \mathrm{Fe}$ II $\lambda 1145$ at $3444 \AA$, Si II $\lambda 1193$ at $3590 \AA$ (possible), Si II $\lambda 1260$ at $3792 \AA, \mathrm{~N} V$ $\lambda 1238$ at $3726 \AA$ (possible), and C II $\lambda 1334$ at $4014 \AA$. (291) York et al. (1991) give this component a B rating, as (212) SBS88 only identified the C IV doublet. For the $z_{a b s}=2.0097$ component, we confirm Ly $\alpha$ absorption at $3659 \AA$, or $z_{a b s}=2.0101$. We also find Fe II $\lambda 1145$ at $3446 \AA$, Si III $\lambda 1206$ at $3632 \AA$, and O I $\lambda 1302$ at $3918 \AA$. (291) York et al. (1991) assign this system an A rating since (212) SBS88 identified both C IV and Si IV $\lambda 1393$ at this redshift. In our spectrum, the Ly $\alpha$ lines for the components of this complex are within $5 \AA$ of a third line, which, if identified as Ly $\alpha$ as well, gives $z_{a b s}=2.0060$. However, we detect only one other line (Si II $\lambda 1260$ at $3788 \AA$ ) for this redshift. This, and the fact that(212) SBS88 find no C IV at $z_{a b s}=2.0060$ lead us to regard this additional identification as extremely uncertain.
(241) SS92 (cf. Section C.2) find no Mg II systems in their spectrum of this object although they note that for the SBS88 systems at $z_{a b s}=1.7666,1.9287,2.0083$, and 2.0097, these lines would have been visible in their spectrum if present. In fact, SS92 find no absorption features in their spectrum at all.
(17) Beaver et al. (1991), hereafter B91, observed the far-UV spectrum of this object using the Faint Object Spectrograph (FOS) on the Hubble Space Telescope (HST). The spectra range from $1630 \AA$ to $2428 \AA$ and were taken using two different
apertures each resulting in $\sim 8.0 \AA$ resolution. In addition, optical spectra were obtained with the Lick telescope. These spectra cover $3250-6350 \AA$ at $15 \AA$ resolution and $3540-4120 \AA$ at $1.8 \AA$ resolution. (17) B91 confirm the $z_{a b s}=0.7800$ system of SBS88 with their identification of Ly $\alpha$ at $2161 \AA$ and $\operatorname{Ly} \beta$ at $1836 \AA$ as well as their tentative identifications of C II $\lambda 1334$ at $2370 \AA$, and Si III $\lambda 1206$ at $2148 \AA$ and their possible identification of C III $\lambda 977$ at $1736 \AA$. They also report one other system:
$z_{a b s}=2.1348$ - The optical spectra of (17) B91 show strong absorption at $3810 \AA$ which is identified as Ly $\alpha$. This identification results in the coincidence of the N V doublet at this redshift with the Mg II doublet at $z_{a b s}=0.3892$ identified by (212) SBS88. This system is corroborated by the tentative identification of Ne VIII $\lambda 770$ at $2417 \AA$ and the uncertain identification of He I $\lambda 584$ at $1836 \AA$. We identify several lines for this associated absorber, including Ly $\alpha$ at $3810 \AA$, O VI $\lambda \lambda 1031,1037$ at $3234 \AA$ and $3253 \AA$, N II $\lambda 1083$ at $3397 \AA$, and N V $\lambda \lambda 1238,1242$ at $3883 \AA$ and $3896 \AA$. Also, as noted by (17) B91, the spectrum of (212) SBS88 shows some absorption near the position of the C IV doublet at this redshift ( $\sim 4860 \AA$ ) but they do not identify this feature.

We identify one additional system in our data:
$z_{a b s}=0.3628$ - This system consists of Fe II $\lambda 2382, \lambda 2586$, and $\lambda 2600$ at $3249 A$, $3525 \AA$, and $3542 \AA$ respectively, as well as Mg II $\lambda \lambda 2796,2803$ at $3810 \AA$ and $3821 \AA$. (17) B91 do not detect $\mathrm{Ly} \alpha$ for this system in their FOS spectrum, however, its position at $1657 \AA$ would place it at the very blue edge of their data where the signal-to-noise ratio is poor.

$$
\text { C. } 7 \text { Q 0153+744 } \quad z_{e m}=2.341
$$

According to our searches, there is no previously published spectrum of this QSO. In our spectrum, we find only one possible metal line system, an associated absorber at $z_{a b s}=2.3456$. We consider this identification tentative, however, due to the fact that
the $\operatorname{Ly} \beta$ line for this system is separated from the position of Ly $\alpha$ by $6 \sigma$. The other species detected are O VI $\lambda 1031$ and $\lambda 1037$ at $3453 \AA$ and $3472 \AA$, Fe II $\lambda 1143$ and Fe II $\lambda 1145$ at $3826 \AA$ and $3831 ~ \AA$, and Si III $\lambda 1206$ at $4037 \AA$. In addition, our red spectrum (see Paper II) does show a possible C IV doublet at $5179 \AA$ and $5188 \AA$, but the doublet ratio is less than one.

## C. 8 Q 0226-038 $\quad z_{e m}=2.073$

The absorption line spectrum of this QSO has been studied by many authors. The first such investigation was undertaken by (42) Carswell et al. (1976) using spectrograms spanning a wavelength range from $3200 \AA$ to $6000 \AA$. (294) Young, Sargent, and Boksenberg (1982b), YSB82 hereafter, obtained spectra from $3530 \AA$ to $5070 \AA$ with $2.2 \AA$ resolution. In addition, (140) Lanzetta, Turnshek, \& Wolfe (1987), LTW87 hereafter, obtained spectra from $6271 \AA$ to $8766 \AA$ with $4.5 \AA$ resolution and a signal-to-noise ratio between 18 and 32. This object was also observed by (241) SS92 with their red setup and by (212) SBS88 (cf. Section C. 2 and Section C.6).

The spectrum we obtained for this object is, unfortunately, riddled with bad columns from the CCD. Therefore, we find no absorption systems from our data alone; instead, we use our spectrum to attempt to confirm the systems found by other authors:
$z_{a b s}=1.3284-$ (241) SS92 confirm the Mg II identification for this system which was found by (140) LTW87. (241) SS92 also identify Fe II $\lambda 2344, \lambda 2382$, and $\lambda 2600$ in their red spectrum. They further corroborate this system by noting that lines found by (294) YSB82 at $3606 \AA$ and $3611 \AA$ can be identified as the C IV doublet and that an unidentified line found by (212) SBS88 at $3890 \AA$ can be identified as Al II $\lambda 1670$. Our data show the C IV $\lambda 1548$ line at $3604 \hat{A}$, but we find only a weak feature at the expected position of $\lambda 1550$. The position of AI II $\lambda 1670$ falls on a bad column in our data. There is a feature at $3555 \AA$, the expected position of Si II $\lambda 1526$; but it is not
identified as a significant line as it falls on another of the many bad columns.
$z_{a b s}=1.3558-(294)$ YSB82 propose the identification of two lines, at $3647 \AA$ and $3654 \AA$, in the Lyman $\alpha$ forest region of their spectrum with the C IV doublet at this redshift. We confirm the presence of these lines; however, given the lack of any other lines to strengthen this identification, the does not meet our criteria for a true metal line system.
$z_{a b s}=2.0435-(212)$ SBS88 identify this system based on the identification of the Si IV and C IV doublets. The expected position of Ly $\alpha$ for this redshift falls on a bad column in our data; and we find only one other possible line for this redshift, Si III $\lambda 1206$ at $3672 \AA$.

We do not confirm the absorption line at $3703 \AA$ reported by Carswell et al. (1976)

## C. 9 Q 0348+061 $\quad z_{e m}=2.056$

(212) SBS88 (cf. Section C.6) find several absorption systems in their spectrum of this QSO ( $3880 \AA-5060 \AA$ ):
$z_{a b s}=0.3997$ - This system is a single Mg II doublet according to (212) SBS88. We find only marginal evidence for a Mg II doublet at $3912 \AA$ and $3921 \AA$ from our red spectrum of this object (see Paper II).
$z_{a b s}=1.7975-(212)$ SBS88 find a C IV doublet at this redshift. We verify Ly $\alpha$ absorption at $3400 \AA$; we detect a possible Si III $\lambda 1206$ line at $3374 \AA$; and our red spectrum shows the C IV doublet identified by (212) SBS88 at $4328 \AA$ and $4336 \AA$.
$z_{a b s}=1.8409-(212)$ SBS88 find another C IV doublet at this redshift. We detect Ly $\alpha$ absorption at $3453 \AA$, in agreement with this system. A possible Si II $\lambda 1260$ line at $3581 \AA$ is found for this redshift; and our red spectrum corroborates the $C$ IV doublet found by (212) SBS88 as well as showing Si IV $\lambda 1393$ at $3958 \mathcal{A}$ (but no $\lambda 1402$ ) and a possible Si II $\lambda 1526$ line at $4335 \AA$.

$$
z_{a b s}=1.9681-(212) \text { SBS88 find a C IV doublet along with C II } \lambda 1334 \text { and a }
$$

possible Si IV $\lambda 1393$ line at this redshift. We find Ly $\alpha 3608 \AA$, Si III $\lambda 1206$ at $3581 \AA$, and a very tentative N V doublet at $3676 \AA$ and $3687 \AA$, which, if present, is highly blended with Ly $\alpha$ at $z_{a b s}=2.0238$ and $z_{a b s}=2.0331$. Our red spectrum verifies the identifications of (212) SBS88 listed above and also shows Fe II $\lambda 1608$ at $4775 \AA$.
$z_{a b s}=2.0237-(212)$ SBS88 find a C IV doublet and possible Si IV $\lambda 1393$ at this redshift. (241) SS92 (cf. Section C.2) confirm this system in their red spectrum ( $5128 \AA-8947 \AA$ ) of this object with the detection of a Mg II doublet at this redshift. They do not detect Mg II for any of the other SBS88 redshifts to which their spectrum is sensitive $\left(z_{a b s}>0.83\right.$.) We detect Ly $\alpha$ absorption at $3676 \AA$, in agreement with this system. In addition, we identify a possible blended Si II $\lambda 1193$ line at $3608 \AA, N$ I $\lambda 1200$ at $3628 \AA$, Si III $\lambda 1206$ at $3648 \AA$, Si II $\lambda 1260$ at $3812 \AA$, and C II $\lambda 1334$ at $4035 \AA$. Our red spectrum exhibits the features found by (212) SBS88 listed above as well as C II $\lambda 1334$ at $4037 \AA$.
$z_{a b s}=2.0330-(212)$ SBS88 identify both C IV and Si IV doublets for this redshift. We detect Ly $\alpha$ at $3687 \AA$ and Si III $\lambda 1206$ at $3659 \AA$. Our red spectrum shows marginal evidence for the features listed by (212) SBS88.

## C. 10 Q 0400+258 $z_{\text {em }}=2.108$

No previously published absorption line spectrum of this QSO was found in our searches. Unfortunately, the low signal-to-noise of the blue portion of our spectrum ( $3208 \AA-3659 \AA$ ) prevents us from identifying any lines in the Lyman alpha forest. We find only one significant line at $3752 \AA$ from which we cannot identify any metal line systems.

## C. 11 Q 0747+610 $z_{e m}=2.491$

In their catalog of QSO absorption lines, (124) Junkkarinen et al. (1991) note two metal line systems found for this object by (2) Afanasjev et al. (1979). These systems were identified at $z_{a b s}=1.986$ and $z_{a b s}=2.210$. (291) York et al. (1991) give both of these systems a $B$ rating in their reference catalog of heavy element systems in QSO spectra. According to their explanation of their rating system, this B rating indicates that either a C IV or Mg II doublet was identified for these systems with the correct doublet ratio, but that no other lines but Lyman alpha were detected. However, (124) Junkkarinen et al. note that for the $z_{a b s}=1.986$ system, N V, Si II, C II , Si IV, and Al II lines were detected in addition to H I and C IV; and for the $z_{a b s}=2.210$ system, Si II', N V, C II, Si IV, and Al III lines were detected in addition to H I and C IV. (241) SS92 (cf. Section C.2) do not confirm either of these metal line system redshifts. Instead, they find three others at $z_{a b s}=1.1282, z_{a b s}=2.0076$, and $z_{a b s}=2.4865$.

We confirm the $z_{a b s}=1.986$ system of (2) Afanasjev et al. (1979) with our identification of Ly $\alpha$ at $3629 \AA$, a possible N I $\lambda 1135$ at $3389 \AA$, a possible Si II $\lambda 1190$ at $3554 \AA$, Si II $\lambda 1193$ at $3562 \AA$, and N I $\lambda 1200$ at $3582 \AA$. We also confirm their $z_{a b s}=2.210$ system with our detection of Ly $\alpha$ at $3903 \AA$, a possible N II $\lambda 1083$ line at $3480 \AA$, Si III $\lambda 1206$ at $3874 \AA$, Si II $\lambda 1260$ at $4047 \AA$, and $O$ I $\lambda 1302$ at $4180 \AA$.

We do not find any lines at the position of the $z_{a b s}=1.1282$ system of SS92 which they identify by a weak Mg II doublet. We identify a metal line system at $z_{a b s}=2.0071$, in accordance with the $z_{a b s}=2.0076$ system found by these authors. At this redshift, we find a strong Ly $\alpha$ line at $3656 \AA$, Si II $\lambda 1190$ and $\lambda 1193$ at $3580 \AA$ and $3589 \AA$, Si III $\lambda 1206$ at $3629 \AA$, Si II $\lambda 1260$ and $\lambda 1304$ at $3791 \AA$ and $3923 \AA$, O I $\lambda 1302$ at $3915 \AA$, and possible C II $\lambda 1334$ absorption at $4014 \AA$. It is clear that some of these Si II lines are blends given their relative strengths. Our confirmation of the $z_{a b s}=2.4865$ system of SS92 is not as strong. We find Ly $\alpha$ and $\mathrm{Ly} \beta$ at $4237 \AA$ and
$3575 \AA$ respectively for this redshift. But we do not detect any other species with any confidence.

The absorption line spectrum of this object is a rich one. We find a total of 145 significant lines and we find twelve metal line systems in addition to the ones discussed above. As is the case for all of our objects, it is unlikely that all of these systems are real since SS92 do not report any lines from their red spectrum at these redshifts. However, we have kept all the systems that cannot be definitively ruled out on the basis of our data. For all redshifts below 1.742, the Ly $\alpha$ line falls outside the spectral range of our data. The values of these redshifts are based upon the strongest line that was detected for each system.
$z_{a b s}=1.4102$ - This system is based upon a C IV doublet at $3731 \AA$ and $3738 \AA$ and a Si IV doublet at $3359 \AA$ and $3381 \AA$. We also find AI II $\lambda 1670$ at $4028 \AA$.
$z_{a b s}=1.4529-$ The value for this redshift is based upon a C IV doublet at $3798 \AA$ and $3804 \AA$. In addition, we detect Si IV $\lambda 1393$ at $3419 \AA$ and Si IV $\lambda 1402$ at $3441 \AA$ (though it must be a blend if it is present otherwise the Si IV doublet ratio is less than one), Si II $\lambda 1526$ at $3745 \AA$, and Al II $\lambda 1670$ at $4098 \AA$.
$z_{a b s}=1.5986$ - For this system, we identify Si II $\lambda 1304$ at $3389 \AA$, possible C II $\lambda 1334$ absorption at $3466 \AA$, a possible Si IV $\lambda 1393$ line at $3621 \AA$ (no $\lambda 1402$ is found), Si II $\lambda 1526$ at $3967 \AA$, and a possible, weak C IV $\lambda 1548$ line at $4023 \AA$. A weak feature is present at the position of C IV $\lambda 1550$, but it is not identified as a significant ( $3 \sigma$ ) line.
$z_{a b s}=1.6822$ - This redshift is based upon Si II $\lambda 1260$. We also find a possible blended N V $\lambda 1242$ line at $3333 \AA$ ( $\lambda 1238$ is out of the wavelength range of our line list), O I $\lambda 1302$ at $3492 \AA$, Si II $\lambda 1304$ at $3498 \AA$, C II $\lambda 1334$ at $3580 \AA$, and a rather doubtful Si IV doublet at $3738 \AA$ and $3761 \dot{A}$.
$z_{a b s}=1.7324-$ This system, based on a possible C IV doublet at $4230 A$ and $4237 \AA$, is a relatively tentative one due to the inconsistent doublet ratios of this pair and of a possible Si IV doublet at $3808 \AA$ and 3833 A. We also find O I $\lambda 1302$ at

3558 A.
$z_{a b s}=1.8123$ - For this system, we find Ly $\alpha$ at $3419 \AA$. In addition, we find a possible Si II $\lambda 1193$ line at $3357 \AA$, Si III $\lambda 1206$ at $3393 \AA$, a possible blended Si II $\lambda 1260$ line at $3544 \AA, O$ I $\lambda 1302$ at $3662 \AA$, and C II $\lambda 1334$ at $3753 \AA$.
$z_{a b s}=1.8728$ - This system consists of Ly $\alpha$ at $3492 \AA$, Si II $\lambda 1190$ and $\lambda 1193$ at $3419 \AA$ and $3428 \AA$, N I $\lambda 1200$ at $3447 \AA$, Si III $\lambda 1206$ at $3466 \AA$, a possible N V $\lambda 1238$ line at $3558 \AA$, Si II $\lambda 1260$ at $3621 \AA, \mathrm{C}$ II $\lambda 1334$ at $3833 \AA$ and a possible Si IV $\lambda 1393$ at $4003 \AA$ (no $\lambda 1402$ component is found.)
$z_{a b s}=2.0070,2.0093-$ We find a metal line system of two components at these redshifts. The first component shows Ly $\alpha$ at $3656 \AA, \mathrm{Si}$ II $\lambda 1190$ and $\lambda 1193$ at $3580 \AA$ and $3589 \AA$, a possible Si III $\lambda 1206$ line at $3618 \AA$, Si II $\lambda 1260$ and $\lambda 1304$ at $3791 \AA$ and $3923 \AA$, C II $\lambda 1334$ at $4014 \AA$, and Si IV $\lambda 1393$ at $4192 \AA$. The $\lambda 1402$ component of this doublet is blended with the same line corresponding to the other system at $z_{a b s}=2.009$. The second component consists of Ly $\alpha$ at $3658 \AA$, a possible $N V \lambda 1238$ line at $3728 \AA$ (no $\lambda 1242$ line is found), Si II $\lambda 1260$ at $3792 \AA$, C II $\lambda 1334$ at $4015 \AA$, and a tentative Si IV doublet at $4194 \AA$ and $4221 \AA$ (with a doublet ratio less than one due to blending.)
$z_{a b s}=2.0476-$ This system is composed of Ly $\alpha$ at $3705 \AA$, N I $\lambda 1200$ at $3656 \AA$ (blended with Ly $\alpha$ at $z_{a b s}=2.007$ if present), Si III $\lambda 1206$ at $3677 \AA$, O I $\lambda 1302$ at $3967 \AA$, and Si IV $\lambda 1393$ at $4247 \AA$.
$z_{a b s}=2.1391-$ At this redshift, we identify Ly $\alpha$ at $3816 \AA$, N I $\lambda 1135$ and $\lambda 1200$ at $3562 \AA$ and $3767 \AA$, and a possible N V doublet at $3889 \AA$ and $3901 \AA$ for which the $\lambda 1242$ component must be blended as it is stronger than both the $\lambda 1238$ component of the doublet and Lya.
$z_{a b s}=2.1724$ - This system consists of Ly $\alpha$ at $3856 \AA$, tentative N I $\lambda 1135$ and $\lambda 1200$ lines at $3601 \AA$ and $3808 \AA$, Si III $\lambda 1206$ at $3828 \AA$, and a possible C II $\lambda 1334$ line at $4235 \AA$.
$z_{a b s}=2.2849$ - This system is identified on the basis of strong Ly $\alpha$ absorption at
$3993 \AA, \mathrm{Ly} \beta$ at $3369 \AA, \mathrm{O}$ VI $\lambda 1031$ and $\lambda 1037$ at $3389 \AA$ and $3408 \AA$, possible Si II $\lambda 1190$ and $\lambda 1193$ lines at $3777 \AA$ and $3786 \AA$, and a possible Si III $\lambda 1206$ line at 3964 A.

## C. 12 Q 0836+710 $z_{e m}=2.218$

(247) Stickel \& Kühr (1993) report an absorption feature in their spectrum of this object at $5360 \AA$ which they identify as the Mg II doublet at $z_{a b s}=0.914$. We find Al III $\lambda 1854$ at $3550 \AA$. Also, we have a red spectrum of this object in the vicinity of Mg II emission. This spectrum does show the Mg II doublet at $5359 \AA$ and $5372 \AA$, giving a redshift of 0.916 .

We find several other redshift systems in our data:
$z_{a b s}=1.4256-$ This system is a double-component C IV absorber with the Si IV doublet at $3380 \AA$ and $3403 \AA$, the C IV doublet at $3755 \AA$ and $3762 \AA$, a possible Si II $\lambda 1526$ at $3702 \AA$, and Fe II $\lambda 1608$ at $3902 \AA$ Tंwo components in each line are evident in the spectrum, with the second, weaker component at $z_{a b s}=1.4249$ which, unlike the first component, shows Al II $\lambda 1670$ absorption, at $4051 \AA$.
$z_{a b s}=1.6681-$ At this redshift, we detect absorption from Ly $\alpha$ at $3243 \mathrm{~A}, \mathrm{C}$ II $\lambda 1334$ at $3561 \AA$, and a Si IV doublet at $3719 \AA$ and $3742 \AA$ (though its implied doublet ratio is less than one.) There is no Mg II absorption in our red spectrum.
$z_{a b s}=1.7331-$ This system consists of Ly $\alpha$ at $3322 \AA$, O I $\lambda 1302$ at $3558 \AA$, the N V doublet at $3386 \AA$ and $3397 \AA$, and a possible Si IV $\lambda 1393$ line at $3809 \AA$. The expected position of the Mg II doublet falls on a poorly subtracted sky line in the red spectrum.

We find a two-component associated absorption system at $z_{a b s}=2.1800$ consisting of only $\operatorname{Ly} \alpha(3866 \AA$ ) and $\operatorname{Ly} \beta(3261 \AA$ and $3263 \AA$.)

The absorption features at $3964 \AA, 3970 \AA, 3975 \AA$, and $3983 \AA$ are identified as traps in the CCD.

## C. 13 Q 0848+153 <br> $$
z_{e m}=2.014
$$

(294) YSB82 (cf. Section C.8) find eight absorption lines blueward of Ly $\alpha$ emission in their spectrum of this QSO. They do not identify any of them. (212) SBS88 (cf. Section C.6) detect only one line in their spectrum of this object (one which is not found by YSB88.) (241) SS92 (cf. Section C.2) find four absorption features in their red spectrum and identify three of them as a Mg II doublet and Fe II $\lambda 2600$ at $z_{a b s}=1.0254$. Neither we nor YSB82 nor SBS88 observed the region of the spectrum necessary to confirm the C IV doublet for this system; but we do identify Fe II $\lambda 1608$ at $3259 \AA$. We find no other lines at this redshift or any other metal line systems from our data. We do note that lines 8 and 11 in our line list match the position of the Si IV doublet at $z_{\mathrm{abs}}=1.5738$ well, although we cannot call this a true metal line system based on our criteria.

## C. 14 Q 0936+368 <br> $$
z_{e m}=2.025
$$

We have found no previously published spectrum of this object. Due to low signal-tonoise in the blue region of our spectrum ( $3200-3400 \AA$ ) the spectrum was truncated at roughly $3400 \AA$ for the purposes of the line list. The absorption features at $3942 \AA$, $3948 \AA$, and $3955 \AA$ are traps in the CCD.

The only system found is a C IV doublet at $4001 \AA$ and $4006 \AA$ and C II $\lambda 1334$ at $3448 \AA$ from a system at $z_{a b s}=1.5841$.

$$
\text { C. } 15 \quad \text { Q } 0952+335 \quad z_{e m}=2.504
$$

Our spectrum of this object shows a damped Lyman alpha system at $3765 \AA$ with an observed equivalent width of $30.97 \AA$. The absorption features at $4277 \AA, 4282 \AA$, $4286 \AA$, and $4290 \AA$ are traps in the CCD. We find ten possible metal line systems:
$z_{a b s}=0.5393-$ This system consists of several Fe II lines ( $\lambda 2344$ at $3609 \AA, \lambda 2374$ at $3655 \AA, \lambda 2382$ at $3668 \AA, \lambda 2586$ at $3981 \AA$, and $\lambda 2600$ at $4002 \AA$ ) and a possible Mg II doublet at $4304 \AA$ and $4314 \AA$. However, these Mg II lines are weaker than all of the Fe II lines identified, contrary to what is expected; and the relative strengths of the Fe II lines are also not entirely consistent with the expected values. Although the possibility of blending keeps us from ruling out this system altogether, it is a tentative one.
$z_{a b s}=1.5362-$ This redshift is based upon a C IV $\lambda 1548$ line at $3927 \AA$. The expected position of C IV $\lambda 1550$ for this redshift falls on a bad column in the data. We also detect a Si IV doublet at $3535 \AA$ and $3558 \AA$, Si II $\lambda 1526$ at $3872 \AA$, Fe II $\lambda 1608$ at $4079 \AA$, and Al II $\lambda 1670$ at $4237 \AA$.
$z_{a b s}=2.0399$ - For this system, we find Ly $\alpha$ at $3695 \AA$, Si III $\lambda 1206$ at $3668 \AA, \mathrm{C}$ II $\lambda 1334$ at $4055 \AA$, and the Si IV doublet at $4237 \AA$ and $4265 \AA$. Also, the position of the N V doublet falls within the damped Lyman alpha line at $3763 \AA$.
$z_{a b s}=2.0555-$ Ly $\alpha$ for this system is found at $3714 \AA$. We also identify Fe II $\lambda 1145$ absorption at $3498 \AA$, possible Si III $\lambda 1206$ absorption at $3687 \AA$, possible Si II $\lambda 1260$ and $\lambda 1304$ absorption at $3850 \AA$ and $3985 \AA$, and a Si IV doublet at $4258 \AA$ and 4286 A.
$z_{a b s}=2.0965-$ This system is the damped Ly $\alpha$ absorber noted above. The metal lines found at this redshift include Si II $\lambda 1190$ and $\lambda 1193$ at $3685 \AA$ and $3695 \AA$ (possible), a N I $\lambda 1200$ line at $3714 \AA$, Si III $\lambda 1206$ at $3735 \AA$, Si II $\lambda 1260$ at $3903 \AA$, C II $\lambda 1334$ at $4130 \AA$, and $\operatorname{Si}$ IV $\lambda \lambda 1393,1402$ at $4314 \AA$ and $4342 \AA$.
$z_{a b s}=2.1670-$ For this system, we find Ly $\alpha$ at $3850 \AA$, Fe II $\lambda 1143$ and $\lambda 1145$ at $3620 \AA$ and $3626 \AA, N$ I $\lambda 1200$ at $3801 \AA$, and Si III $\lambda 1206$ at $3820 \AA$.
$z_{a b s}=2.1850-$ This system consists of Ly $\alpha$ at $3872 A, S i \operatorname{II} \lambda 1193$ at $3801 A, N$ I $\lambda 1200$ at $3820 \AA$, Si II $\lambda 1260$ and $\lambda 1304$ at $4014 \AA$ and $4153 \AA$, and O I $\lambda 1302$ at $4147 \AA$.
$z_{a b s}=2.2102-$ At this redshift, we detect Ly $\alpha$ at $3903 \AA$, Si II $\lambda 1190$ and $\lambda 1193$
at $3820 \AA$ and $3830 \AA$, Si III $\lambda 1206$ at $3872 \AA$, a possible $\mathrm{N} V \lambda 1238$ line at $3976 \AA$ (no $\lambda 1402$ component is found), a blended Si II $\lambda 1260$ line at $4046 \AA$, and O I $\lambda 1302$ at $4180 \AA$. The expected position of Si II $\lambda 1304$ falls on a bad column in the data.
$z_{a b s}=2.2924-$ For this system, we identify Ly $\alpha$ at $4002 \AA, \mathrm{~N}$ II $\lambda 1083$ at $3569 \AA$, Si III $\lambda 1206$ at $3972 \AA$, and the N V doublet at $4079 \AA$ and $4092 \AA$.
$z_{a b s}=2.3189-$ This system consists of $\operatorname{Ly} \alpha$ at $4035 \AA$, Fe II $\lambda 1143$ and $\lambda 1145$ at $3795 \AA$ and $3801 \AA$, Si II $\lambda 1193$ at $3959 \AA$, and Si II $\lambda 1260$ at $4183 \AA$.

## C. 16 Q 0955 $+472 \quad z_{e m}=2.482$

We note the presence of associated absorption in the spectrum of this radio loud QSO, at $4203 \AA, 4206 \AA, 4219 \AA$, and $4241 \AA$, separated from the position of the Lyman alpha emission by $2121 \mathrm{~km} \mathrm{~s}^{-1}, 1910 \mathrm{~km} \mathrm{~s}^{-1}, 990 \mathrm{~km} \mathrm{~s}^{-1}$, and $-539 \mathrm{~km} \mathrm{~s}^{-1}$, respectively. We do not find metal line systems consistent with these redshifts, but we do find Ly $\beta$ absorption in our spectrum for the first, third, and fourth systems listed above at $3547 \AA, 3561 \AA$, and $3579 \AA$. The Ly $\beta$ line for the second system appears to be blended with Ly $\beta$ for the first system at $3549 \hat{A}$, but is not identified as a significant line by our line-finding program. The metal line systems we find are as follows:
$z_{a b s}=1.7251-$ This system is identified on the basis of a possible C IV doublet at $4219 \AA$ and $4225 \AA$. The other metal lines detected are O I $\lambda 1302$ at $3547 \AA$ and Si II d 1304 at $3554 \AA$. This system is relatively insecure.
$z_{a b s}=2.2849$ - For this system, we find Ly $\alpha$ at $3993 \AA$, N II $\lambda 1083$ at $3561 \AA$, blended N I $\lambda 1200$ absorption at $3943 \AA$, Si III $\lambda 1206$ at $3963 \AA$, and a possible N V doublet for which the $\lambda 1238$ component is blended with the Lyman alpha complex at 4071 A , and the $\lambda 1242$ component is detected at 4082 A .
$z_{a b s}=2.3453,2.3481-$ Ly $\alpha$ for this system is part of the Lyman alpha complex at 4067 A. Other lines detected include a possible, blended N I $\lambda 1135$ line and N I $\lambda 1200$
at $3796 \AA$ and $4014 \AA$, Fe II $\lambda 1145$ at $3830 \AA$, Si II $\lambda 1190$ and $\lambda 1193$ at $3984 \AA$ and $3993 \AA$, Si III $\lambda 1206$ at $4038 \AA$, and a possible N V doublet at $4144 \AA$ and $4156 \AA$.
$z_{a b s}=2.4087-$ This system consists of Ly $\alpha$ at $4144 \AA, \mathrm{~N}$ I $\lambda 1135$ and $\lambda 1200$ at $3869 \AA$ and $4090 \AA$, and Si III $\lambda 1206$ at $4112 \AA$. Despite the fact that the putative N I $\lambda 1135$ line shows good redshift agreement with this system, it is treated as a possible identification because the stronger line of the same species, N I $\lambda 1200$, shows poorer agreement.

The absorption features at $4277 \AA, 4282 \AA, 4286 \AA$, and $4290 \AA$ are traps in the CCD.

## C. 17 Q 0956+122 $z_{e m}=3.308$

Sargent et al. (1989) obtained a spectrum of this object with $4 \AA$ resolution from $3150 \AA$ to $4700 \AA$ and $6 \AA$ resolution from $4600 \AA$ to $7000 \AA$. They find weak C IV systems at $z_{a b s}=2.9145$ and $z_{a b s}=3.2230$. We find only Ly $\alpha$ at $z_{a b s}=2.9156$. The system at $z_{a b s}=3.2230$ is identified as a Lyman limit system by Steidel (1990) from a higher resolution ( $\sim 1.1 \AA$ ) spectrum. He identifies C IV and Si IV doublets, Si III $\lambda 1206$, C III $\lambda 977$ and several Lyman series lines. We confirm this system with our detection of Ly $\alpha$ at $5134 \AA$, N I $\lambda 1200$ at $5069 \AA$, and Si III $\lambda 1206$ at $5095 \AA$. Songaila \& Cowie (1996) identify this system as a partial Lyman limit system at $z_{a b s}=3.2216$. Sargent et al. (1989) also find a Lyman limit system with no corresponding heavy element lines at $z_{a b s}=3.096$. We identify strong Ly $\alpha$ absorption at this redshift as well as a possible Si II $\lambda 1260$ line at $5162 \AA$. Both of these lines are found in the spectrum of Steidel (1990), but they are not attributed to a Lyman limit system. Instead, Steidel (1990) finds another Lyman limit system at $z_{a b s}=3.11$. We detect strong Lyman alpha absorption at this redshift as well as Si III $\lambda 1206$. The position of Si II $\lambda 1260$ falls on a trap in the CCD. Several other metal line systems were also found by this author:
$z_{a b s}=0.0456$ - Our spectrum does not extend far enough into the red to allow us to confirm the Na I $\lambda \lambda 5891,5897$ lines tentatively identified at this redshift.
$z_{a b s}=2.3104$ - Steidel (1990) tentatively identifies Ly $\alpha$, C IV $\lambda 1548$ and Al II $\lambda 1670$ at this redshift. We find C II $\lambda 1334$ at $4418 \AA$, a double-component Si IV doublet at $4614 \AA$ and $4636 \AA$, Si II $\lambda 1526$ at $5054 \AA$, and C IV $\lambda 1548$ and $\lambda 1550$ (blended with Ly $\alpha$ at $z_{a b s}=3.223$ ) at $5125 \AA$ and $5134 \AA$, Hu et al. (1995) identify this double-component Si IV doublet as well in a high resolution ( $\sim 0.13 \AA$ ) spectrum taken with the HIRES Spectrograph on the Keck Telescope. The $\lambda 1393$ line is seen at $z_{a b s}=2.3104$ and $z_{a b s}=2.3109$.
$z_{a b s}=2.7169$ - Steidel (1990) finds C II $\lambda 1334$, a C IV doublet, and Al II $\lambda 1670$ at this redshift. We confirm this system with the detection of Ly $\alpha$ at $4519 \AA, N$ I $\lambda 1200$ at $4461 \AA$, Si III $\lambda 1206$ at $4484 \AA$, the N V doublet at $4604 \AA$ and $4618 \AA$, and C II $\lambda 1334$ at $4959 \AA$. The position of O I $\lambda 1302$ falls on a bad region in the spectrum.
$z_{a b s}=2.7261-$ Steidel (1990) finds a weak C IV doublet at this redshift. We do not find Ly $\alpha$ corresponding to this redshift.
$z_{a b s}=2.8320-$ Steidel (1990) finds a weak C IV doublet at this redshift as well as $\mathrm{Ly} \beta$, Si II $\lambda 1260$, and C II $\lambda 1334$. We identify Ly $\alpha$ at $4659 \AA, \mathrm{~N}$ I $\lambda 1200$ at $4599 \AA$, Si II $\lambda 1260$ at $4830 \AA$, a possible Si II $\lambda 1304$ line at $5002 A$ (blended with Ly $\alpha$ at $z=3.1145$ ), O I $\lambda 13024990 \AA$, and a possible C II $\lambda 1334$ line at $5118 \AA$.
$z_{a b s}=3.1045-$ Steidel (1990) identifies Ly $\alpha$, C III $\lambda 977$, and the C IV doublet for this secure system. We confirm strong Ly $\alpha$ absorption at $4990 \AA$ and find a Si II $\lambda 1260$ line at $5172 \AA$.
$z_{a b s}=3.1530-$ Steidel (1990) finds a weak C IV doublet, a Si IV doublet, Si II $\lambda 1190$ and $\lambda 1193$, Si III $\lambda 1206$, and several Lyman series lines. We detect Ly $\alpha$ at $5048 \AA$, a possible N I $\lambda 1200$ line at $4980 \AA$ (blended with Ly $\alpha$ at $z_{a b s}=3.0963$ ), a tentative Si III $\lambda 1206$ line at $5012 \AA$, and the N V doublet at $5144 \hat{A}$ and $5157 \AA$. We detect the features identified by Steidel (1990) as Si II $\lambda 1190$ and $\lambda 1193$, but since our spectrum shows no feature at the position of Si II $\lambda 1260$, we do not confirm those

## identifications.

We identify several other possible metal line systems from our spectrum:
$z_{a b s}=2.8342-$ This system is separated by $172 \mathrm{~km} \mathrm{~s}^{-1}$ from the system found by Steidel (1990) at $z_{a b s}=2.8320$. Ly $\alpha$ is detected at $4661 \AA$, the N V doublet at $4750 \AA$ and $4765 \AA$, and Si II $\lambda 1260$ at $4832 \AA$. The Si II $\lambda 1304$ and C II $\lambda 1334$ identified with the $z_{a b s}=2.8320$ system are more likely associated with this system.
$z_{a b s}=3.0490-$ This system consists of Ly $\alpha$ at $4922 \AA$, possible Fe II $\lambda 1143$ and $\lambda 1145$ lines at $4630 \AA$ and $4636 \AA$, Si III $\lambda 1206$ at $4884 \AA$ and Si II $\lambda 1260$ at $5103 \AA$. Steidel (1990) finds no line which would correspond to Fe II $\lambda 1608$ at $\sim 6510 \AA$ or C IV at $\sim 6270 \AA$.
$z_{a b s}=3.0528-$ At this redshift, we identify Ly $\alpha$ at $4927 \AA, N$ I $\lambda 1135$ and $\lambda 1200$ at $4599 \AA$ and $4862 \AA$, Si III $\lambda 1206$ at $4890 \AA$, and the N V doublet at $5021 \AA$ and $5036 \AA$. There is a line in the Steidel (1990) line list at $6274 \AA$, which would correspond to C IV $\lambda 1548$ at this redshift, but none at $6285 \AA$, which would correspond to C IV $\lambda 1550$.
$z_{a b s}=3.1321-$ This system is composed of Ly $\alpha$ at $5023 \AA$, a possible N II $\lambda 1083$ line at $4480 \AA, N$ I $\lambda 1135$ and $\lambda 1200$ at $4689 \AA$ and $4959 \AA$, a possible $N V$ doublet, both components of which are blended with other lines (see line list), at $5118 \AA$ and $5134 \AA$, and Si II $\lambda 1260$ at $5208 \AA$. No C IV is detected by Steidel (1990).
$z_{a b s}=3.1975-$ At this redshift, we detect Ly $\alpha$ at $5103 \AA$, N I $\lambda 1200$ at $5036 \AA, \mathrm{Si}$ III $\lambda 1206$ at $5065 \AA$, and a possible N V doublet at $5200 \AA$ and $5217 \AA$. A feature at $6497 \AA$ in the line list of Steidel (1990) would correspond to C IV $\lambda 1548$ at this redshift, but no $\lambda 1550$ component is present.
$z_{a b s}=3.2461$ - This system consists of Ly $\alpha$ at $5162 \AA$, Fe II $\lambda 1143$ and $\lambda 1145$ at $4855 \AA$ and $4862 \AA$ : N I $\lambda 1135$ and $\lambda 1200$ at $4753 \AA$ and $5095 \AA$, and Si III $\lambda 1206$ at $5122 \AA$. Steidel (1990) finds no C IV doublet or Fe II $\lambda 1608$ at this redshift.
$z_{a b s}=3.2774-$ At this redshift, we identify Ly $\alpha$ at $5200 \AA$, N II $\lambda 1083$ at $4636 \AA$, N I $\lambda 1135$ and $\lambda 1200$ at $4855 \AA$ and $5134 \AA$, and Si III $\lambda 1206$ at $5162 \AA$. Steidel
(1990) finds no C IV at this redshift.

The absorption features at $5176 \AA, 5181 \AA, 5185 \AA$, and $5189 \AA$ are identified as traps in the CCD.

## C. 18 Q 1009+299 $\quad z_{e m}=2.633$

There are no previously published absorption line spectra of this object. From our data, we find eight candidate metal line systems including a complex of associated absorption near the quasar redshift:
$z_{a b s}=1.8484$ - This system is identified by the C IV doublet at $4410 \AA$ and $4418 \AA$, the $\lambda 1550$ component of which is blended with Ly $\alpha$ at $z_{a b s}=2.6339$. Other lines found include O I $\lambda 1302$ at $3709 \AA$, Si II $\lambda 1304$ and $\lambda 1526$ at $3715 \AA$ and $4349 \AA$.
$z_{a b s}=2.2611$ - For this system, we identify Ly $\alpha$ at $3964 \AA$, Si III $\lambda 1206$ at $3934 \AA$, Si II $\lambda 1260$ at $4110 \AA$, O I $\lambda 1302$ at $4246 \AA$, and a possible C II $\lambda 1334$ line at $4353 \AA$. The expected positions of Fe II $\lambda 1143$ and $\lambda 1145$ fall on bad columns in the data.
$z_{a b s}=2.3582$ - This system is comprised of Ly $\alpha$ at $4082 \AA, \mathrm{~N}$ I $\lambda 1200$ at $4030 \AA$, Si III $\lambda 1206$ at $4052 \AA$, Si II $\lambda 1260$ at $4232 \AA$, and O I $\lambda 1302$ at $4373 \AA$.
$z_{a b s}=2.3809-$ At this redshift, we detect Ly $\alpha$ at $4110 \AA, N$ II $\lambda 1083$ at $3665 \AA, N$ I $\lambda 1200$ at $4056 \AA$, Si III $\lambda 1206$ at $4079 \AA$, a possible $N V \lambda 1242$ line at $4201 \AA$ (the expected position of the $\lambda 1238$ component falls on a bad region in the spectrum), and O I $\lambda 1302$ at $4403 \AA$.
$z_{a b s}=2.4068$ - For this system, we identify very strong, weakly damped damped Ly $\alpha$ absorption at $4141 \AA$, Si II $\lambda 1190$ at $4056 \AA$ (the position of Si II $\lambda 1193$ falls on a bad region in the spectrum), N I $\lambda 1200$ at $4087 \AA$ A, Si III $\lambda 1206$ at $4110 \AA$, Si II $\lambda 1260$ at $4294 \AA$, and O I $\lambda 1302$ at $4436 \AA$. The position of Si II $\lambda 1304$ falls on a bad column.
$z_{a b s}=2.5236-$ At this redshift, we identify Ly $\alpha$ at $4283 \hat{A}, \mathrm{~N}$ I $\lambda 1135$ at $3998 \AA, \mathrm{Si}$ II $\lambda 1193$ at $4205 \AA, N$ I $\lambda 1200$ at $4227 \AA$, and Si III $\lambda 1206$ at $4252 \AA$. The expected
position of Si II $\lambda 1260$ falls on bad columns in the data.
$z_{a b s}=2.5531-$ This system consists of Ly $\alpha$ at $4319 \AA, \operatorname{Ly} \beta$ at $3645 \AA$, O VI $\lambda 1031$ and $\lambda 1037$ at $3667 \AA$ and $3686 \AA$, N II $\lambda 1083$ at $3851 \AA$, Fe II $\lambda 1143$ at $4061 \AA$ (the position of $\lambda 1145$ falls on bad columns in the spectrum), and Si II $\lambda 1193$ at $4240 \AA$.
$z_{a b s}=2.6158$ - For this associated absorber, $\operatorname{Ly} \alpha$ is found at $4396 \AA, \operatorname{Ly} \beta$ at $3709 \AA$, C II $\lambda 1036$ at $3746 \AA$, possible Fe II $\lambda 1143$ and Fe II $\lambda 1145$ blended with Ly $\alpha$ at $z_{a b s}=2.40677$ at $4134 \AA$ and $4141 \AA$, and Si III $\lambda 1206$ at $4362 \AA$.

The absorption features at $4412 \AA, 4418 \AA, 4422 \AA$, and $4425 \AA$ are identified as traps in the CCD.

## C. 19 Q 1207+399 $z_{e m}=2.459$

According to our literature searches, there is no previously published absorption line spectrum of this QSO. From our data, we find two metal line systems:
$z_{a b s}=2.1116-$ At this redshift, we detect a blended Ly $\alpha$ line at $3781 \AA, \mathrm{Si}$ III $\lambda 1206$ at $3765 \AA$, Si II $\lambda 1260$ at $3922 \AA$, C II $\lambda 1334$ at $4152 \AA$, Si IV $\lambda \lambda 1393,1402$ at $4337 \AA$ and $4365 \AA$, and a possible C IV $\lambda 1548$ line at $4816 \hat{A}$. The expected position of C IV $\lambda 1550$ for this redshift falls just outside our spectral range.
$z_{a b s}=2.1561-$ At this redshift, we find Ly $\alpha$ at $3837 \AA, \operatorname{Ly} \beta$ at $3238 \AA, \operatorname{Si}$ III $\lambda 1206$ at $3808 \AA$, the $N$ V doublet at $3907 \AA$ and $3922 \AA$, Si II $\lambda 1260$ at $3977 \AA$, and C II $\lambda 1334$ at $4212 \AA$.

The absorption features present at $4576 \AA, 4587 \AA, 4595 \AA$ and $4603 \AA$ are traps in the CCD.

$$
\text { C. } 20 \quad \text { Q } 1210+175 \quad z_{e m}=2.564
$$

This QSO was observed by (86) Foltz et al. (1987) who noted a possible damped Lyman alpha system in their spectrum at roughly 3500 A. According to Wolfe et al. (1995) this system is a confirmed damped Ly $\alpha$ absorber with an equivalent width
of $11.3 \AA$. Ly $\alpha$ for this candidate is not within our spectral range for this object. However, we find five metal line systems from our data, one of which is consistent with this damped system.
$z_{a b s}=1.8917$ - This system is the damped Ly $\alpha$ absorber discussed above. Ly $\alpha$ at this redshift is outside our spectral range, but we do detect the Si IV doublet at $4030 \AA$ and $4056 \AA$. Other lines detected include Si II $\lambda 1260, \lambda 1304$, and $\lambda 1526$ at $3645 \AA, 3772 \AA$, and $4414 \AA$, O I $\lambda 1302$ at $3765 \AA$, and C II $\lambda 1334$ at $3859 \AA$.
$z_{a b s}=2.0548-$ At this redshift, we identify Ly $\alpha$ at $3713 \AA, \mathrm{Si}$ II $\lambda 1193, \lambda 1260$, and $\lambda 1304$ at $3645 \AA, 3850 \AA$, and $3985 \AA$, and C II $\lambda 1334$ at $4076 \AA$. The Si II $\lambda 1304$ line must be a blend if it is present.
$z_{a b s}=2.1240$ - For this system, we detect Ly $\alpha$ at $3798 \AA$, Si III $\lambda 1206$ at $3768 \AA$, a N V doublet at $3868 \AA$ and $3881 \AA$, a possible Si II $\lambda 1260$ line at $3938 \AA$, and C II $\lambda 1334$ at $4169 \AA$.
$z_{a b s}=2.1974$ - For this system, we identify Ly $\alpha$ at $3887 \AA$, N I $\lambda 1200$ at $3837 \AA$, Si III $\lambda 1206$ at $3859 \AA$, Si II $\lambda 1260$ at $4030 \AA$, O I $\lambda 1302$ at $4164 \AA$, and C II $\lambda 1334$ at $4266 \AA$.
$z_{a b s}=2.5786$ - This system consists of $\mathrm{Ly} \alpha$ at $4350 \AA, \mathrm{Ly} \beta$ at $3671 \AA$, and O VI $\lambda 1031$ and $\lambda 1037$ at $3693 \AA$ and $3714 \AA$. Both O VI lines are stronger than Ly $\alpha$ and $\operatorname{Ly} \beta$ indicating either that they are blends or that the line of sight through this absorber intersects regions dominated by highly ionized gas. The latter interpretation is likely because the redshift of this absorber is larger than the QSO emission redshift, indicating that this absorbing material must be infalling gas associated with the QSO itself.

$$
\text { C. } 21 \quad \text { Q } 1231+294 \quad z_{e m}=2.018
$$

(259) Thompson et al. (1989) measure an emission redshift of $z_{e m}=2.011 \pm 0.001$ for this QSO from [O IV]+Si IV $\lambda \lambda 1397-1406$ and C III] $\lambda 1909$ emission lines. Our
spectrum of Ly $\alpha$ emission gives a redshift of $\sim 2.018$.
We find two metal line systems from our absorption line spectrum.
$z_{a b s}=1.4780-$ This system consists of the C IV doublet at $3836 \AA$ and $3843 \AA$ and the Si IV doublet at $3454 \AA$ and $3477 \AA$.
$z_{a b s}=1.8755$ - For this system, we identify Ly $\alpha$ at $3496 \AA$, possible N I $\lambda 1135$ and $\lambda 1200$ lines at $3264 \AA$ and $3450 \AA$, a possible Fe II $\lambda 1145$ line at $3292 \AA$, and O I $\lambda 1302$ at $3745 \AA$, blended with C IV $\lambda 1550$ at $z_{a b s}=1.4145$.

Lastly, we identify a C IV doublet at $z_{a b s}=1.4145$ and a C IV doublet at $z_{a b s}=$ 1.1672 along with Al II $\lambda 1670$ at $3621 \AA$, though we detect no other lines at these redshifts. The absorption features at $3937 \AA, 3942 \AA, 3946 \AA$, and $3950 \AA$ are traps in the CCD. The feature at $3722 \AA$ is spurious as well, and it most likely a cosmic ray.

## C. 22 Q 1323-107 $z_{e m}=2.360$

The only previously published spectrum found for this object is a spectrum including Ly $\alpha$ and C IV emission from (138) Kunth et al. (1981). They find an emission redshift of 2.360 for the QSO. We find four candidate metal line systems from our absorption line spectrum:
$z_{a b s}=1.4244-$ This system is based upon the Si IV doublet at $3379 \AA$ and $3401 \AA$. At this redshift, we also detect C II $\lambda 1334$ at $3235 \AA$ and Si II $\lambda 1526$ at $3701 \AA$. No C IV doublet is detected.
$z_{a b s}=1.4727$ - This system is identified by the C IV doublet at $3828 \AA$ and $3835 \AA$. Other lines detected include O I $\lambda 1302$ at $3220 \hat{A}$ and C II $\lambda 1334$ at $3300 ~ A$.
$z_{a b s}=1.4922-$ This system is based upon the C IV doublet at $3858 \AA$ and $3864 \AA$. Due to the large uncertainty in the position of the line center for the $\lambda 1550$ component, the redshifts of the doublet components agree to within $<1 \sigma$. We also detect O I $\lambda 1302$ at $3246 \AA$, possible Si II $\lambda 1304$ and $\lambda 1526$ lines at $3250 \AA$ and $3803 \AA$ respectively,
and Fe II $\lambda 1608$ at $4008 \AA$. Our red spectrum of this object (see Paper II) actually extends slightly blueward of $1.0 \AA$ resolution blue spectrum and shows a possible Si II $\lambda 1260$ line at $3144 \AA$.
$z_{a b s}=1.8415-$ This system consists of Ly $\alpha$ at $3454 \AA$, N I $\lambda 1135$ and $\lambda 1200$ at $3225 \AA$ and $3409 \AA$, a possible O I $\lambda 1302$ line at $3701 \AA$, Si II $\lambda 1260$ and $\lambda 1304$ at $3582 \AA$, and $3706 \AA$ respectively, and C II $\lambda 1334$ at $3792 \AA$. The Si II $\lambda 1260$ line must be blended because its equivalent width is larger than that of Ly $\alpha$. The N I and Si II line matches have been retained despite poor redshift agreement between the two lines of the same species due to the fact the errors in the line centers of lines 32 ( N I $\lambda 1200$ ) and 64 (Si II $\lambda 1260$ ) are large enough for these redshifts to agree to within $\sim 3 \sigma$. Our red spectrum shows no lines redward of Ly $\alpha$ for this system.

## C. 23 Q 1329+412 $z_{\text {em }}=1.934$

(212) SBS88 (cf. Section C.6) find six absorption line systems in their spectrum of this object. (241) SS92 (cf. Section C.2) confirm two of these systems and find another. These are the systems these authors report and the additional information gained from our spectrum:
$z_{a b s}=0.5009-$ (212) SBS88 regard this system as probable from their identification of the Mg II doublet. The only search lines that fall in our spectral range for this redshift are Fe II $\lambda 2344-\lambda 2600$. We find none of these.
$z_{a b s}=1.2821-$ This system is identified by (241) SS92 from a strong Mg II doublet. The spectrum of (212) SBS88 did not cover the region of C IV absorption, but ours does and we find no significant lines that would correspond to the C IV doublet at this redshift.
$z_{a b s}=1.4716-$ This system is identified by (212) SBS88 on the basis of an "unambiguous" C IV doublet. (241) SS92 find no Mg II absorption at this redshift. We confirm the C IV doublet identification of (212) SBS88 and also find a
tentative O I $\lambda 1302$ line at $3217 \AA$.
$z_{a b s}=1.6010-(212)$ SBS88 find a strong C IV doublet at this redshift which they note is likely to be blended with another C IV doublet at a nearby redshift. (241) SS92 identify the Mg II doublet at this redshift. Our spectrum shows the strong C IV doublet found by (212) SBS88 in addition to Si II $\lambda 1260$ at $3279 \AA$, C II $\lambda 1334$ at $3471 \AA$, and the Si IV doublet at $3625 \AA$ and $3648 \AA$. In addition, we find that the position of the C IV $\lambda 1548$ for $z_{a b s}=1.5980$ corresponds to a significant line in our spectrum while the $\lambda 1550$ component at this redshift appears to be strongly blended with C IV $\lambda 1548$ at $z_{a b s}=1.6007$.
$z_{a b s}=1.8359-$ This system is identified by (212) SBS88 by the C IV doublet and confirmed by (241) SS92 who find the Mg II doublet at $z_{a b s}=1.8355$. We detect Ly $\alpha$ at $3447 \AA$, a possible Fe II $\lambda 1145$ line at $3246 \AA$, possible Si II $\lambda 1193$ and $\lambda 1260$ lines at $3384 \AA$ and $3575 \AA$, and C II $\lambda 1334$ at $3785 \AA$.
$z_{a b s}=1.8401$ - This system is identified by (212) SBS88 on the basis of a C IV doublet. (241) SS92 do not detect Mg II. We do detect a strong Ly $\alpha$ line consistent with this redshift at $3453 \AA$.
$z_{a b s}=1.9406-(212)$ SBS88 identify this system on the basis of the C IV doublet. (241) SS92 do not observe the spectral region encompassing Mg II at this redshift; but we detect Ly $\alpha$ at $3575 \AA$ and a N V doublet at $3643 \AA$ and $3654 \AA$. This system, having a redshift larger than the QSO emission redshift, is probably associated with the QSO.

The absorption features at $3969 \AA, 3974 \AA, 3979 \AA$, and $3983 \AA$ are traps in the CCD.

We detect a possible C IV doublet redward of Ly $\alpha$ emission but blueward of the spectral range of (241) SS92 at a redshift of 1.35285 . The components are detected at $3643 \AA$ and $3648 \AA$ along with Fe II $\lambda 1608$ at $3785 \AA$. The $\lambda 1548$ component of the doublet coincides with $\mathrm{N} V \lambda 1238$ at $z_{a b s}=1.9404$; and the $\lambda 1550$ component coincides with the Si II $\lambda 1402$ for the well-established system at $z_{a b s}=1.6010$ described
above. No other lines are found. Also, we find another possible C IV doublet in the Ly $\alpha$ forest at $z_{a b s}=1.2480$; but no other lines are detected at this redshift either.

Lastly, (144) Lanzetta, Wolfe, \& Turnshek (1995) report a damped Lyman alpha system at $z_{a b s}=0.5193$ in the IUE spectrum of (142) Lanzetta, Turnshek, \& Sandoval (1993). Again, the only lines in our spectral range for this redshift are Fe II $\lambda 2344$ $\lambda 2600$. We detect only the strongest of these lines, Fe II $\lambda 2382$ at $3621 \AA$.

## C. 24 Q 1337+285 $z_{e m}=2.541$

Our literature search yielded no previously published optical spectrum of this QSO. From our spectrum, we detect two possible heavy metal absorption systems:
$z_{a b s}=2.5081$ - This relatively secure system consists of Ly $\alpha$ at $4265 \AA, \operatorname{Ly} \beta$ at $3598 \AA$, possible O VI $\lambda 1031$ and $\lambda 1037$ lines at $3619 \AA$ and $3640 \AA$, C II $\lambda 1036$ at $3636 \AA$, N II $\lambda 1083$ at $3803 \AA$, a possible Fe II $\lambda 1145$ line at $4017 \AA$, and Si II $\lambda 1190$ and $\lambda 1193$ at $4176 \AA$ and $4186 \AA$.
$z_{a b s}=2.5228$ - For this system, we detect Ly $\alpha$ at $4283 \AA, \operatorname{Ly} \beta$ at $3614 \AA$, O VI $\lambda 1031$ at $3636 \AA$, possible N I $\lambda 1135$ and $\lambda 1200$ lines at $3998 \AA$ and $4226 \AA$, Fe II $\lambda 1143$ and $\lambda 1145$ at $4027 \AA$ and $4033 \AA$, and Si III $\lambda 1206$ at $4249 \AA$.

The absorption features at $4339 \AA, 4344 \AA, 4347 \AA$, and $4352 \AA$ are traps in the CCD.

$$
\text { C. } 25 \text { Q 1346-036 } \quad z_{e m}=2.362
$$

The spectrum of this QSO blueward of Ly $\alpha$ emission has been studied by (294) YSB82 (cf. Section C.8). We confirm all the absorption features seen by these authors with the exception of the line they detect at $3844 \AA$ which falls on a bad region in our spectrum. They find no metal line absorbers from their data, but suggest a possible Mg II doublet at $z_{a b s}=0.4453$. We detect this tentative doublet at 4043 A and $4054 \AA\left(z_{a b s}=0.4458\right)$ but find no Fe II absorption at this redshift. We detect the
$4051 \AA$ line reported by (294) YSB82, but identify Mg II $\lambda 2803$ with the absorption feature at $4054 \AA$ for better redshift agreement.
(140) LTW87 (cf. Section C.8) report no absorption features in their red ( $6250 \AA$ $-8350 \AA$ ) spectrum of this object. And (284) W86 (cf. Section C.3) find no damped Lyman alpha candidates in their $3200 \AA-5200 \AA$ spectrum.

The only additional identifications we make for this object are are two Ly $\alpha$-Ly $\beta$ pairs at $3965 \AA$ and $3345 \AA\left(z_{a b s}=2.2616\right)$ and at $4028 \AA$ and $3450 \AA\left(z_{a b s}=2.3630\right)$. For the $z_{a b s}=2.2616$ pair, the Ly $\beta$ line is stronger than Ly $\alpha$ and must be a blend; also, our red spectrum (see Paper II) shows the C IV doublet for this system at $5050 \AA$ and $5058 \AA$. The $z_{a b s}=2.3630$ redshift is larger than the QSO emission redshift indicating that it must be associated with the QSO, although not an associated absorber per se, as it shows no metal lines Our red spectrum does not show the C IV doublet at this redshift.

## C. 26 Q 1358+115 $\quad z_{e m}=2.589$

(284) W86 (cf. Section C.3) find several $4 \sigma$ absorption features in their $10 \AA$ resolution spectrum of this object. We confirm these lines with the exception of the features they report at $3573 \AA, 3874 \AA$, and $4092 \AA$. We also confirm the feature they report at $4074 \AA$ having less than $4 \sigma$ significance.

We find six possible metal line systems from our data:
$z_{a b s}=0.5084-$ This system is a Mg II absorber for which the doublet is detected at $4218 \AA$ and $4228 \AA$. The $\lambda 2803$ component of the doublet is blended with Ly $\alpha$ at $z_{a b s}=2.4778$. We also detect Fe II $\lambda 2382$ and $\lambda 2600$ at $3593 \AA$ and $3922 \AA$ and Mg I $\lambda 2853$ at 4303 A .
$z_{a b s}=2.4158$ - This system is composed of a strong Ly $\alpha$ line at $4152 \AA$, possible Si II $\lambda 1190$ and $\lambda 1193$ lines at $4065 \AA$ and $4075 \AA$, a N I possible $\lambda 1200$ line at $4098 \AA$, and Si III $\lambda 1206$ at $4121 \AA$. The expected position of N I $\lambda 1135$ for this redshift falls
on a bad column in the data.
$z_{a b s}=2.5559$ - For this system, we find Ly $\alpha$ at $4323 \AA, \operatorname{Ly} \beta$ at $3647 \AA$, Si II $\lambda 1190$ and $\lambda 1193$ at $4234 \AA$ and $4243 \AA$, N I $\lambda 1200$ at $4266 \AA$, and Si III $\lambda 1206$ at $4290 \AA$.
$z_{a b s}=2.5630$ - This system is composed of Ly $\alpha$ at $4331 \AA, \operatorname{Ly} \beta$ at $3655 \AA$ and Si II $\lambda 1190$ and $\lambda 1193$ at $4241 \AA$ and $4251 \AA$. The Si II $\lambda 1193$ line is blended with Ly $\alpha$ at $z_{a b s}=2.4968$.
$z_{a b s}=2.5763-$ At this redshift, we find an associated absorber showing Ly $\alpha$ at $4348 \AA, \mathrm{Ly} \beta$ blended with the feature at $3672 \AA\left(\mathrm{Ly} \beta\right.$ at $\left.z_{a b s}=2.5799\right)$, O VI $\lambda 1031$ and $\lambda 1037$ at $3689 \AA$ and $3709 \AA$.
$z_{a b s}=2.5799-$ This system is another associated absorber for which we identify $\operatorname{Ly} \alpha$ at $4353 \AA, \operatorname{Ly} \beta$ at $3672 \AA$, and O VI $\lambda 1031$ and $\lambda 1037$ at $3694 \AA$ and $3714 \AA$.

## C. 27 Q 1406+492 $z_{e m}=2.161$

Literature searches yielded no previously published absorption spectrum of this QSO. From our data, we find two possible heavy element absorption systems:
$z_{a b s}=1.4330-$ This redshift is based upon the C IV doublet at $3767 \AA$ and $3773 \AA$. We also detect the Si IV doublet at $3391 \AA$ and $3411 \AA$. However, the Si IV $\lambda 1402$ line must be a blend (possibly with Si IV $\lambda 1393$ at $z_{a b s}=1.4474$ ) due to its equivalent width relative to the $\lambda 1393$ component and its poor redshift agreement with it.
$z_{a b s}=1.4470-$ This system is another C IV absorber for which the C IV doublet is found at $3788 \AA$ and $3795 \AA$. We also find C II $\lambda 1334$ at $3266 \AA$, the Si IV doublet for which the $\lambda 1393$ component lies at $3411 \AA$ and the $\lambda 1402$ component is blended with the feature at $3435 \AA$, Si II $\lambda 1526$ at $3736 \AA$, and Fe II $\lambda 1608$ at $3936 \AA$.

A C IV doublet is found at at $z_{a b s}=1.5253$; and we find a $\operatorname{Ly} \alpha, \operatorname{Ly} \beta$ pair due to an absorber at $z_{a b s}=2.1540$. The absorption features present at $3962 \mathrm{~A}, 3967 \mathrm{~A}$, $3968 \AA, 3974 \AA, 3978 \AA$, and $3981 \AA$ are traps in the CCD.

## C. 28 Q 1408+009 $z_{\text {em }}=2.260$

According to a literature search, this is the first published spectrum of this object. Five possible metal line systems are found:
$z_{a b s}=1.3158$ - This system is identified by a Si IV doublet at $3228 \AA$ and $3248 \AA$ as well as Si II $\lambda 1526$ absorption at $3535 \AA$ and a Fe II $\lambda 1608$ line at $3725 \AA$.
$z_{a b s}=1.5190$ - This system is a C IV absorber with $\lambda 1548$ identified at $3900 \AA$ and $\lambda 1550$ at $3906 \AA$. Also found are C II $\lambda 1334$ at $3363 \AA$ and $\operatorname{Si}$ II $\lambda 1526$ at $3843 \AA$.
$z_{a b s}=1.6929-$ This system consists of Ly $\alpha$ at $3274 \AA$, Si III $\lambda 1206$ at $3248 \AA, \mathrm{Si}$ II $\lambda 1260$ at $3394 \AA$, and O I $\lambda 1302$ at $3506 \AA$. Despite the fact that this Ly $\alpha$ line is relatively strong ( $E W_{0}=1.153 \AA$ ) all of the other lines identified are stronger, creating the need to invoke the possibility of blending for all of them. For this reason, this system is considered uncertain.
$z_{a b s}=1.9956-$ At this redshift, we detect $\operatorname{Ly} \alpha$ at $3642 \AA$, N I $\lambda 1200$ at $3595 \AA, \mathrm{Si}$ II $\lambda 1260$ and $\lambda 1304$ at $3774 \AA$ and $3906 \AA$, and O I $\lambda 1302$ at $3900 \AA$.
$z_{a b s}=2.1991$ - For this system, we identify Ly $\alpha$ at $3889 \AA$, a blended $\operatorname{Ly} \beta$ line at $3282 \AA$, Si III $\lambda 1206$ at $3859 \AA$, and Si II $\lambda 1260$ at $4032 \AA$.

The absorption features at $4575 \AA, 4586 \AA, 4602 \AA$ are traps in the CCD.

## C. 29 Q 1421+330 $\quad z_{e m}=1.905$

The rest-UV absorption spectrum of this object has been studied by many authors. (275) Weymann et al. (1979) find C IV in their $2.5 \AA$ resolution spectrum at $z_{a b s}=$ 1.462, but not the expected Si IV and C II absorption. This redshift is confirmed by (133) Koratkar et al. (1992) and by our data. We find Si IV at $3433 \AA$ and $3455 \AA$ and C IV at $3813 \AA$ and $3820 \AA$.
(268) Uomoto (1984) finds several tentative systems in his red spectrum of this QSO:
$z_{a b s}=0.2249-(268)$ Uomoto (1984) detects a Mg II doublet at this reshift. Our spectrum shows this identification to be unlikely given the implied velocity separation of the doublet lines ( $\sim 310 \mathrm{~km} \mathrm{~s}^{-1}$ ) if they are associated with the features at $3428 \AA$ and $3433 \AA$ in our data.
$z_{\mathrm{abs}}=0.3236-(268)$ Uomoto (1984) finds a Mg II doublet at this redshift. Our spectrum does not show these lines, nor any others at this redshift.
$z_{a b s}=0.9030$ - (268) Uomoto (1984) finds several Fe II lines at this redshift, $\lambda 2344, \lambda 2374, \lambda 2382, \lambda 2586$, and $\lambda 2600$. Also, Mn II $\lambda 2594 \AA$ and a Mg II doublet are detected. This Mg II doublet is confirmed by (241) SS92 (cf. Section C.2.) Our spectrum shows Al III $\lambda 1854$ and $\lambda 1862$ absorption at $3530 \AA$ and $3544 \AA$.
$z_{a b s}=1.1732$ - (268) Uomoto (1984) finds a Mg II doublet at this redshift which is confirmed by (241) SS92. We find Si II $\lambda 1526$ at $3318 \AA$; but no C IV or Al III.
$z_{a b s}=1.2252$ - (268) Uomoto (1984) finds a C IV doublet at this redshift. We detect absorption at the position of the $\lambda 1548$ component, but none at the position of $\lambda 1550$.
(85) Foltz et al. (1986) find four additional systems in their $1 \AA$ resolution spectrum covering $3820 \AA$ to $4035 \AA$ :
$z_{a b s}=0.4565-\mathrm{A} \mathrm{Mg}$ II doublet is detected at this redshift. These lines should fall at the very red edge of our spectrum. While there are some possible features present, we are not able to confirm this system.
$z_{a b s}=1.5847-$ A C IV doublet is detected at this redshift. We detect O I $\lambda 1302$ at $3368 \AA$, C IV $\lambda 1548$ at $4001 \AA$, and an apparent absorption feature, but no significant line, at the position of C IV $\lambda 1550$.
$z_{a b s}=1.7177$ - (85) Foltz et al. (1986) find a C IV doublet and Al II $\lambda 1670$ at this redshift. We confirm this system with our detections of Ly $\alpha$ at $3304 A$, Si III $\lambda 1206$ at $3279 \AA$, and O I $\lambda 1302$ at $3539 \AA$.
$z_{a b s}=1.7590-(85)$ Foltz et al. (1986) detect a C IV doublet at this redshift. We detect a Ly $\alpha$ line consistent with this system at $3355 \AA$.
(45) Caulet (1989) detects C IV at four redshifts including $z_{a b s}=1.7171$ and $z_{a b s}=1.4621$ (see above). The other systems detected are $z_{a b s}=1.7010$ and $z_{a b s}=$ 1.7755 for which we detect no Ly $\alpha$ absorption.

Lastly, (144) Lanzetta et al. (1995) report a possible Lyman limit absorber in their IUE spectrum at $z_{L L S}=1.4798$. We find possible absorption features at the positions of OI $\lambda 1302$, Si II $\lambda 1304$, and Si II $\lambda 1526$ for this redshift. These features are not identified as $3 \sigma$ lines by FINDSL, however. We do not detect C IV, Si IV, or C II.

The absorption features at $3967 \AA, 3972 \AA$, and $3980 \AA$ are traps in the CCD.

## C. 30 Q $1422+231 \quad z_{e m}=3.623$

This object is a gravitationally lensed quasar (Bechtold \& Yee 1995, hereafter BY95.) Therefore, due to uncertainties in the amplification by the lensing, it will only be used for the analysis of the Ly $\alpha$ forest statistics and not in the proximity effect analysis in Paper II.

Bechtold \& Yee (1995) obtained a spectrum of this object from $4818 \AA$ to $5684 \AA$ with $1.8 \AA$ resolution using the Subarcsecond Imaging Spectrograph on the Canada-France-Hawaii Telescope. A red spectrum from $6246 \AA$ to $7179 \AA$ with $2.0 \AA$ resolution was also obtained in order to identify metal line systems using the Red Channel Spectrograph on the Multiple Mirror Telescope. The systems identified by these authors are as follows:
$z_{a b s}=3.091$ - This system is identified by a strong C IV doublet. We detect a marginally consistent doublet at $6323 \AA$ and $6331 \AA$ in our red spectrum (see Paper II). BY95 also find $\mathrm{Ly} \alpha, \mathrm{Si}$ II $\lambda 1193$, N I $\lambda 1200, \mathrm{Si}$ II $\lambda 1260$, and O I $\lambda 1302$. We confirm the Ly $\alpha$ feature at $4973 \hat{A}$ and find features at $4882 \hat{A}, 4907 A .5157 \AA$, and $5328 \AA$, in marginal agreement with the other lines found by these authors. No Si II $\lambda 1190$ is detected by us or BY95. The O I $\lambda 1302$ line, if present, is blended with Ly $\alpha$
at $z_{a b s}=3.3830$.
$z_{a b s}=3.382-$ This system is also based upon a strong C IV doublet seen in the red spectrum of BY95. These authors also identify Ly $\alpha$ and Si II $\lambda 1260$ blended with a double-component Ly $\alpha$ line at $5519 \AA$. We confirm their C IV doublet from our red spectrum; and in our Ly $\alpha$ forest spectrum, we detect a strong Ly $\alpha$ line consistent with this redshift at $5328 \AA$, but do not confirm a Si II $\lambda 1260$ line corresponding to the one found by BY95.
$z_{a b s}=3.515-$ This system is based upon a weak C IV doublet for which BY95 also identify Ly $\alpha$, Si II $\lambda 1190$ and $\lambda 1193$, and Si III $\lambda 1206$. We confirm the Ly $\alpha$ line at $5489 \AA$; we find N I $\lambda 1200$ at $5418 \AA$; but we do not find features corresponding to the Si II and Si III lines above. We do detect weak features at the correct position of C IV for this system in our red spectrum.
$z_{a b s}=3.536,3.538$ - These systems are identified by strong C IV doublets by BY95. We confirm these in our red spectrum, but the two components are not resolved. These authors also identify Ly $\alpha$ and Si III $\lambda 1206$ for both components. We confirm these features, Ly $\alpha$ at $5513 \AA$ and $5517 \AA$, and Si III at $5471 \AA$ and $5475 \AA$; and we make an additional identification of N I $\lambda 1200$ at $5445 \AA$. Songaila \& Cowie (1996) identify a strong redshift system at $z_{a b s}=3.5353$ in their high resolution ( $\sim 0.15 \AA$ ) spectrum taken with HIRES on the Keck Telescope. They are able to derive column densities for several species, including C II, C IV, S II, Si III, Si IV, and N V (upper limit).
$z_{a b s}=3.587-$ BY95 find a weak C IV doublet at this redshift, and we confirm this detection in our red spectrum. They also identify Ly $\alpha$ and Si II $\lambda 1193$. We confirm these features at $5577 \AA$ and $5475 \AA$ and make the additional identifications of N II $\lambda 1083$ at 4973 (blended with Ly $\alpha$ at $z_{a b s}=3.0906$ ), Si III $\lambda 1206$ at 5534 A and N I $\lambda 1200$ at $5504 \AA$. Songaila \& Cowie (1996) find a strong system at $z_{a b s}=3.5862$ and derive column densities for C II, C III (upper limit), C IV, Si II (upper limit), Si III (upper limit), Si IV, and N V (upper limit).
$z_{a b s}=3.624-$ BY95 find another weak C IV doublet at this redshift, along with Ly $\alpha$, Si II $\lambda 1190$ and $\lambda 1193$, and Si III $\lambda 1206$. We detect the weak C IV absorption in our red spectrum. In our Ly $\alpha$ forest spectrum, we confirm Ly $\alpha$ at $5621 \AA$ and the Si II lines at $5504 \AA$ and $5578 \AA$; but we find no Si III line.

Songaila and Cowie identify a third strong redshift system from their data at $z_{a b s}=3.4464$ for which they derive column densities for $\mathrm{CIV}, \mathrm{Si}$ III, and Si IV and upper limits on the column densities for C II, C III, and Si II. We detect a strong C IV doublet in our red spectrum; but in the Ly $\alpha$ forest, we identify only a strong Ly $\alpha$ line at $5407 \AA$ corresponding to this system. These authors also identify a partial Lyman limit system at $z_{a b s}=3.3809$ showing C IV, Si IV. and C II. Our spectrum shows Ly $\alpha$ at $5324 \AA$ and a possible Si II $\lambda 1260$ line at $5522 \AA$.

Lastly, we make two more metal line system identifications based upon strong Ly $\alpha$ absorption in our spectrum:
$z_{a b s}=3.3460-$ This system is composed of Ly $\alpha$ at $5283 \AA$, possible Si II $\lambda 1190$ and $\lambda 1193$ lines at $5174 \AA$ and $5187 \AA$, Si III $\lambda 1206$ at $5244 \AA$, and Si II $\lambda 1260$ at $5477 \AA$.
$z_{a b s}=3.4945-$ At this redshift, we identify Ly $\alpha$ at $5464 \AA$, Fe II $\lambda 1143$ and $\lambda 1145$ at $5137 \AA$ and $5146 \AA$, possible Si II $\lambda 1190$ and $\lambda 1193$ lines at $5348 \AA$ and $5363 \AA$, and N I $\lambda 1200$ at $5392 \AA$.

## C. 31 Q 1435+638 $z_{e m}=2.066$

The absorption line spectrum of this QSO has been studied by several authors. (212) SBS88 (cf. Section C.6) report four C IV systems:
$z_{a b s}=1.4590$ - (212) SBS88 find a weak, possible C IV doublet at this redshift. We confirm this identification, but note that these lines are more likely O I $\lambda 1302$ and Si II $\lambda 1304$ at $z_{a b s}=1.9233$. We find no other lines at this redshift.
$z_{a b s}=1.4792-$ (212) SBS88 find a second weak, possible C IV doublet at this
redshift. Our spectrum shows only the $\lambda 1548$ component at $3837 \AA$. There is a weak absorption feature at the position of the $\lambda 1550$ component, but no significant line is identified. No other lines are found at this redshift.
$z_{a b s}=1.5925-$ (212) SBS88 find a probable C IV doublet at this redshift. We identify O I $\lambda 1302$ at $3376 \AA$ and find a possible, weak absorption feature (but no $3 \sigma$ line) at the position of C II $\lambda 1334$.
$z_{a b s}=1.9235-(212)$ SBS88 regard this C IV doublet as certain. They also find C II $\lambda 1334$ and a possible Si IV $\lambda 1393$ line. We detect a strong Ly $\alpha$ line for this redshift at $3554 \AA$, Si II $\lambda 1260$ at $3685 \AA$, O I $\lambda 1302$ at $3808 \AA$, Si II $\lambda 1304$ at $3813 \AA$, C II $\lambda 1334$ at $3901 \AA$. In addition, (241) SS92 find a strong Mg II doublet at this redshift.
(144) Lanzetta et al. (1995) report no damped Lyman alpha candidates in their ultraviolet spectrum. The absorption features at $3824 \AA$ and $3829 \AA$ are traps in the CCD.

## C. 32 Q 1604+290 $\quad z_{e m}=1.962$

A literature search yielded no previously published absorption line spectrum of this QSO. Our spectrum shows no significant absorption lines. However, the signal-tonoise of the data blueward of Lyman alpha is poor ( $\leq 2$ over the range $3200-3500 \AA$ ) and the spectrum is truncated blueward of $3493 \AA$. The apparent absorption features redward of Ly $\alpha$ emission are identified as traps in the CCD.

## C. 33 Q 1715+535 $z_{e m}=1.932$

The Lyman alpha forest spectrum of this QSO has been studied by several authors. (212) SBS88 (cf. Section C.6) find three systems from their 3750-4930 $\AA$ i spectrum:
$z_{a b s}=0.3673-(212)$ SBS88 identify a Mg II doublet at this redshift. The $\lambda 2796$ component falls on a series of traps in the CCD at $3824 \hat{\AA}$ in our spectrum; and we do not detect the $\lambda 2803$ component. Mg I $\lambda 2853$ coincides with a feature at $3902 \AA$;
but we find no Fe II lines to corroborate this Mg II system, which is therefore still regarded as uncertain. (185) Nelson \& Malkan (1992) find no candidates for this system in their photometric search for [O II] emission from Mg II absorption systems. They do note a galaxy at a redshift of 0.449 , but we detect no Fe II at this redshift. $z_{a b s}=1.6330-(212)$ SBS88 detect a C IV doublet and Si II $\lambda 1526$ at this redshift. Our spectrum shows C II $\lambda 1334$ at $3512 \AA$, and a Si IV doublet at $3669 \AA$ an $3692 \AA$. The IUE spectrum of (142) Lanzetta et al. (1993) appears to show an absorption feature at $\sim 3200 \AA$, which would coincide with Ly $\alpha$.
$z_{a b s}=1.7587-(212)$ SBS88 report a C IV doublet at this redshift as well. We confirm this system with our detections of Ly $\alpha$ at $3354 \AA$ and a possible Si II $\lambda 1260$ line at $3476 \AA$. We find possible weak absorption features at the positions of the Si IV doublet.
(212) SBS88 also report a possible Galactic Ca II $\lambda 3935$ line. We confirm the detection of this line at $3934 \AA$. (241) SS92 (cf. Section C.2) detect no lines in their $5950-8040 \AA$ and $5130-8950 \AA$ spectra of this object.

In addition to the absorption line systems discussed above, we find four other systems from our spectrum:
$z_{a b s}=1.3412-A t$ this redshift, we detect a C IV doublet at $3635 \AA$ and $3631 \AA$ and Al II $\lambda 1670$ at $3911 \AA$. We note the presence of a weak absorption feature (but no $3 \sigma$ line) at the expected position of Si II $\lambda 1526$. Although we find only three lines for this system, the IUE spectrum of (142) Lanzetta et al. (1993) appears to show a feature at $\sim 2850 \AA$ which could be identified with Ly $\alpha$ at this redshift.
$z_{a b s}=1.4711$ - This system consists of a possible C IV $\lambda 1548$ line at $3826 \AA$ (no $\lambda 1550$ absorption is detected), Si II $\lambda 1526$ at $3772 \AA$, and C II $\lambda 1334$ at $3297 \AA$. We find weak features, but no significant lines at the positions of O I $\lambda 1302$ and Si II $\lambda 1304$. Only three line detections for this system are regarded as acceptable as well given a possible absorption line in the IUE spectrum of (142) Lanzetta et al. (1993) at $\sim 3005 \AA$ which can be regarded as Ly $\alpha$ at this redshift.
$z_{a b s}=1.8746-$ For this system, we find Ly $\alpha$ at $3494 \AA$, possible Si II $\lambda 1193$ and $\lambda 1260$ lines at $3431 \AA$ and $3625 \AA$, N I $\lambda 1200$ at $3449 \AA$, and possible Si III $\lambda 1206$ absorption at $3467 \AA$. (241) SS92 find no Mg II $\lambda 2796$ at this redshift.
$z_{a b s}=1.8963-$ At this redshift, we detect Ly $\alpha$ at $3521 \AA$, N I $\lambda 1200$ at $3476 \AA$, a blended Si III $\lambda 1206$ line at $3494 \AA$, and O I $\lambda 1302$ at $3772 \AA$.

The apparent absorption features at $3818 \AA, 3821 \AA, 3824 \AA$, and $3826 \AA$ are identified as traps in the CCD.

## C. 34 Q 2134+004 $z_{e m}=1.941$

We find no previously published spectrum for this object. Our data show 19 absorption lines. Line \#17 is tentatively identified at Mg II $\lambda 2796$ at $z_{a b s}=0.3654$. The $\lambda 2803$ component of the doublet as well as Mg I 2853 coincide with absorption features which are not identified as $3 \sigma$ lines by FINDSL. No Fe II lines are found at this redshift.

## C. 35 Q 2251+244 $z_{e m}=2.359$

(42) Carswell et al. (1976) report one metal line system in their spectrum (3250$5200 \AA$ ) of this object. This system is an associated absorber at $z_{\text {abs }}=2.3638$; and these authors identify Ly $\alpha, \operatorname{Ly} \beta$, C III $\lambda 977$, O VI $\lambda 1031$, N I $\lambda 1200$, N V $\lambda 1238, \mathrm{Si}$ IV $\lambda 1393$, and C IV $\lambda 1548$. This system is confirmed by (15) Barthel et al. (1990) from their $5.0 \AA$ resolution spectrum over the range $3870-7730 \AA$ who detect $\mathrm{Ly} \alpha, \mathrm{N}$ V $\lambda 1238$, Si IV $\lambda 1393$, and C IV $\lambda 1548$ as well. The N V, Si IV, and C IV doublets are also confirmed by (4) Aldcroft et al. (1995). We confirm this system as well with our identifications of $\mathrm{Ly} \alpha$ at $4088 \mathcal{A}, \mathrm{Ly} \beta$ at $3450 \mathcal{A}$ and O VI $\lambda 1031$ and a blended $\lambda 1037$ line at $3470 \AA$ and $3490 \AA$ respectively. In addition, our red spectrum of this object (see Paper II) shows the N V doublet at $4167 \hat{A}$ and $4181 \hat{A}$, the Si IV doublet at $4688 \AA$ and $4718 \AA$, and the C IV doublet at $5205 \AA$ and $5214 \AA$. The region of
the spectrum blueward of $\sim 3290 \AA$ has been removed from our analysis due to low signal-to-noise ( $\leqslant 2$. )
(15) Barthel et al. (1990) report four other systems:
$z_{a b s}=1.7495-$ At this redshift, the authors detect a C IV doublet. We detect only a possible N V $\lambda 1242$ line at $3416 \AA$. Since no lines are detected at shorter wavelengths in our spectrum, no $\lambda 1238$ component is identified. (4) Aldcroft et al. (1995) confirm this system. Our red spectrum does show a possible C IV doublet associated with this system at $4257 \AA$ and $4264 \AA$.
$z_{a b s}=1.0901$ - For this system, the authors identify Fe II $\lambda 2382$, a Mg II doublet and Mg I $\lambda 2852$. Our spectrum shows only a possible Al II $\lambda 1670$ line at $3490 \AA$. The only other lines that fall within the range of our line list are Al III $\lambda 1854$ and $\lambda 1862$, but these are not found. (4) Aldcroft et al. (1995) confirm this system. Our red spectrum confirms the Mg II doublet identification made by (15) Barthel et al. (1990) ( $5842 \AA$ and $5857 \AA$ ) but not the Fe II or the Mg I identifications.
$z_{a b s}=2.1554-$ The authors find C II $\lambda 1334$ and a C IV doublet at this redshift. (4) Aldcroft et al. (1995) confirm this and also detect Si IV $\lambda 1393$. In our spectrum, we identify Ly $\alpha$ for this system at $3835 \AA$, Si II $\lambda 1193$ at $3765 \AA$ (the position of $\lambda 1190$ falls on a bad column in the data), N I $\lambda 1200$ at $3786 \AA$, a possible Si III $\lambda 1206$ line at $3807 \AA$, and Si II $\lambda 1260$ at $3976 \AA$. In addition, our red spectrum shows C II $\lambda 1334$ at $4122 \AA$, Si II $\lambda 1526$ at $4816 \AA$, the C IV doublet at $4885 \AA$ and $4893 \AA, \mathrm{Al}$ II $\lambda 1670$ at $5272 \AA$, and a possible Al III $\lambda 1854$ line at $5272 \AA$. (No Al III $\lambda 1862$ line is found.)
$z_{a b s}=2.3524-$ (15) Barthel et al. (1990) identify C IV and N V doublets at this redshift which are confirmed by (4) Aldcroft et al. (1995). In our spectrum, we identify Ly $\alpha$ at $4074 \AA, \operatorname{Ly} \beta$ at $3438 \AA$, O VI $\lambda 1031$ and $\lambda 1037$ at $3459 \AA$ and $3478 \AA$, and a possible Fe II $\lambda 1145$ line at $3838 \AA$. We also confirm the $N V$ and $C$ IV doublet found by (15) Barthel et al. (1990) from our red spectrum, though the N V doublet we identify has a doublet ratio less than one. In addition, our red spectrum shows O

I $\lambda 1302$ at $4367 \AA$ and C II $\lambda 1334$ at $4475 \AA$.
We also identify a number of other systems from our data:
$z_{a b s}=1.8993$ - This system is composed of $\mathrm{Ly} \alpha$ at $3525 \AA$, possible Si II $\lambda 1190$ and $\lambda 1193$ absorption at $3450 \AA$ and $3459 \AA$, N I $\lambda 1200$ at $3478 \AA$, O I $\lambda 1302$ at $3775 \AA$, and Si II $\lambda 12603653 \AA$. In addition, our red spectrum shows Si II $\lambda 1526$ at $4427 \AA$.
$z_{a b s}=2.0336-$ At this redshift, we identify Ly $\alpha$ at $3688 \AA$, possible, blended Si II $\lambda 1193$ and $\lambda 1260$ lines at $3620 \AA$ and $3824 \AA$, Si III $\lambda 1206$ at $3660 \AA$, and O I $\lambda 1302$ at $3949 \AA$. Our red spectrum shows Si II $\lambda 1526$ at $4631 \AA$, a possible, blended Fe II $\lambda 1608$ line at $4879 \AA$, and Al II $\lambda 1670$ at $5068 \AA$.
$z_{a b s}=2.0570$ - For this system, we find Ly $\alpha$ at $3716 \AA, \mathrm{~N}$ I $\lambda 1135$ (blended) and $\lambda 1200$ at $3470 \AA$ and $3668 \AA$, a blended Si III $\lambda 1206$ line at $3688 \AA$, and the $\mathrm{N} V$ doublet at $3786 \AA$ and $3799 \AA$. Also, our red spectrum shows the Si IV doublet at $4262 \AA$ and $4289 \AA$ as well as Fe II $\lambda 1608$ at $4915 \AA$.
$z_{a b s}=2.1052$ - This system consists of Ly $\alpha$ at $3775 \AA$, Si III $\lambda 1206$ at $3746 \AA$, and Si II $\lambda 1260$ and $\lambda 1304$ at $3913 \AA$ and $4050 \AA$. Our red spectrum shows a possible, blended Al II $\lambda 1670$ line at $5188 \AA$.
$z_{a b s}=2.3158$ - This system is composed of Ly $\alpha$ at $4031 \AA$, a possible O VI $\lambda 1037$ line at $3440 \AA$ ( $\lambda 1031$ is outside the range of the line list), N I $\lambda 1200$ at $3979 \AA$, and Si III $\lambda 1206$ at $4001 \AA$. Our red spectrum extends slightly blueward of the higher resolution $\mathrm{Ly} \alpha$ forest spectrum and shows some evidence for $\mathrm{Ly} \beta$ at $3401 \AA$ and O VI $\lambda 1031$ at $3422 \AA$, as well as Si II $\lambda 1260, \lambda 1304$, and $\lambda 1526$ at $4181 \AA, 4327 \AA$, and $5065 \AA$, O I $\lambda 1302$ at $4319 \AA$, and C II $\lambda 1334$ at $4427 \AA$.

## C. 36 Q 2254+024 $z_{\text {em }}=2.090$

The radio properties and the UV emission lines of this object have been widely studied. (241) SS92 (cf. Section C.2) find no absorption lines in their red spectra (5128$8947 \AA$ ). Due to the poor signal-to-noise ( $\leq 2$ ) of the blue region of our spectrum, only
the portion redward of $3450 \AA$ was used for our line list. We find 25 absorption lines but no metal line systems according to our criteria. Only two possible identifications are made: a C IV doublet at $z_{a b s}=1.4751$ for which the $\lambda 1550$ component must actually blended with the feature at $3837 \AA$; and a Si IV doublet at $z_{a b s}=1.7323$ for which the corresponding Ly $\alpha$ line falls in the low signal-to-noise region of the data and is not seen. However, our red spectrum (see Paper II) does lend some confirmation to the possible $z_{a b s}=1.7323$ system as it shows this Si IV doublet as well as Si II $\lambda 1526$ at $4171 \AA$, a C IV doublet at $4233 \AA$ and $4238 \AA$, and Al II $\lambda 1670$ at $4564 \AA$. No lines redward of Ly $\alpha$ are confirmed for the $z_{a b s}=1.4751$ system.

## C. 37 Q 2310+385 $z_{e m}=2.181$

No previously published spectrum of this QSO was found. Due to poor signal-to-noise blueward of $3571 \AA$, only the portion of the spectrum redward of this wavelength was used for the purposes of our line list. Fifteen significant absorption lines were found, but none of these could be identified with any heavy element absorption systems. Three identifications of doublets redward of Ly $\alpha$ emission could be made: C IV doublets at $z_{a b s}=1.4998$ and $z_{a b s}=1.5036 ;$ and a Mg II doublet at $z_{a b s}=0.3840$.

## C. 38 Q 2320 $+079 \quad z_{e m}=2.088$

We found no previously published spectrum of this object. We find a double component damped Ly $\alpha$ complex in our spectrum at $3712 \AA$ and $3715 \AA$. Each of these components shows Si II $\lambda 1193$ ( $3645 \AA$ ) and Si III $\lambda 1206$ ( $3685 \AA$ and $3687 \AA$.) Si II $\lambda 1190$ is present, but not identified as a $3 \sigma$ line by FINDSL. The feature at $3553 \AA$ is most likely a cosmic ray.

## C. 39 Q 2329-020 $z_{e m}=1.896$

No previously published spectra of this QSO were found. We find 17 significant absorption lines in our spectrum. We make a number of identifications of doublets redward of Ly $\alpha$ emission. Two C IV doublets are seen at $z_{a b s}=1.2902$ and $z_{a b s}=$ 1.2922 , a separation of $\sim 260 \mathrm{~km} \mathrm{~s}^{-1}$. The second doublet also appears to have weak features of Si II $\lambda 1526$ and Al II $\lambda 1670$ associated with it. A strong C IV doublet is also detected at $z_{a b s}=1.3339$ along with weak features at the positions of Si II $\lambda 1526$ and Al II $\lambda 1670$. This QSO also shows associated Ly $\alpha$ absorption at $3509 \AA, 3513 \AA$, $3521 \AA$, and $3531 \AA$, but no metals lines are found at this redshifts.

## C. 40 Data from the Literature

Spectra that met three basic criteria were gathered from the literature. In all cases, the errors were published, the resolution was equal to or better than $200 \mathrm{~km} \mathrm{~s}^{-1}$, and no broad absorption line features were present, which would indicate the presence of material intrinsic to the QSO (see Table 5 of B94). Table 2.2 is a list of the objects chosen to supplement the sample and the reference for each. Figure 2.3 shows histograms of the distribution of QSO redshifts and absorption line redshifts for the total sample.

The line list for the QSO $1603+383$ was provided by Dobrzycki, Engels, \& Hagen (1999) prior to publication. This object has a B magnitude of 15.9.

Appendix D
Figure 4.4 (Continued)





































## References

[1] Abel, T. \& Haehnlet, M. G. 1999, ApJ, 520, L13
[2] Afanasjev, V. L., Karachenstev, I. D., Lipovetsky, V. A., Lorentz, H., \& Stoll, D. 1979, Astron. Nachr., 300, 31
[3] Appenzeller, I., Krautter, J., Mandel, H., Bowyer, S., Dixon, W. V., Hurwitz, M., Barnstedt, J., Grewing, M., Kappelmann, N., \& Krmere, G. 1998, ApJ, 500, L9
[4] Aldcroft, T. L., Bechtold, J., \& Elvis, M. 1994, ApJS, 93, 1
[5] Babu, G. J. \& Feigelson, E. D. 1996, Astrostatistics, (London: Chapman \& Hall)
[6] Bahcall, J. N. \& Salpeter, E. E. 1965, ApJ, 142, 1677
[7] Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., Hartig, G. F., Bohlin, R., Junkkarinen, V. 1991, ApJ, 377, L5
[8] Bahcall, J. N., Bergeron, J., Boksenberg, A., Hartig, G. F., Jannuzi, B. T., Kirhakos, S., Sargent, W. L. W., Savage, B. D., Schneider, D. P., Turnshek, D. A., Weymann, R. J., \& Wolfe, A. M. 1993, ApJS, 87, 1
[9] —— 1996, ApJ, 457, 19
[10] Bajtlik, S., Duncan, R. C., \& Ostriker, J. P. 1988, ApJ, 327, 570 (BDO)
[11] Baker, A. C., Carswell, R. F., Bailey, J. A., Espey, B. R., Smith, M. G., \& Ward, M. J. 1994, MNRAS, 270, 579
[12] Baker, J. C., Hunstead, R. W., Athreya, R. M., Barthel, P. D., de Silva, E., Lehnert, M., \& Saunders, R. D. E. 2001, ApJ, 568, 592
[13] Baldwin, J. A., Wampler, E. J., \& Gaskell, C. M. 1989, ApJ, 338, 630
[14] Bardeen, J. M., Bond, J. R., Kaiser, N., \& Szalay, A. S. 1986, ApJ, 30415
[15] Barthel, P. D., Tytier, D. R., \& Thomson, B. 1990, A\&A, 82, 339
[16] Basu, D. 1994, Ap\&SS, 222, 91
[17] Beaver, E.A., Burbidge, E. M., Cohen, R. D., Junkkarinen, V. T., Lyons, R. W., Rosenblatt, E. I., Hartig, G. F., Margon, B., \& Davidsen A. F. 1991, ApJ, 377, L1 (B91)
[18] Bechtold, J., Weymann, R. J., Lin, Z., \& Malkan, M. A. 1987, ApJ, 315, 180
[19] Bechtold, J. 1994, ApJS, 91, 1 (B94)
[20] Bechtold, J. \& Yee, H. K. 1995, AJ, 110, 1984
[21] Bechtold, J., Dobrzycki, A., Wilden, B., Morita, M., Scott J., Dobrzycka, D., Tran, K. -V., \& Aldcroft, T. L. 2002, ApJ, in press (Paper III)
[22] Becker, Robert H., et al. 2001, AJ, 122, 2850
[23] Bi, H. 1993, ApJ, 405, 479
[24] Bi, H. \& Davidsen, A. 1997, ApJ, 479, 523
[25] Bianchi, S., Cristiani, S., \& Kim, T. -S. 2001, A\&A, 376, 1
[26] Bland-Hawthorn, J., Taylor, K., Veilleux, S., \& Shopbell, P. L. 1994, ApJ, 437, L95
[27] Bolton, J. G., Peterson, B. A., Wills, B. J., Wills, D. 1976, ApJ, 210, L1
[28] Boyle, B. J. 1991 in Proc. 1990 Texas/ESO-CERN Symp. on Relativistic Astrophysics,Cosmology, and Fundamental Physics, ed. J. D. Barrow, L. Mestel, \& P. A. Thomas (Ann. NY Acad. Sci., 647, 14)
[29] Boyle, B. J., Shanks, T., Croom, S. M., Smith, R. J., Miller, L., Loaring, B., \& Heymans, C. 2000, MNRAS, 317, 1014
[30] Boyle, B. J., Jones, L. R. \& Shanks, T. 1991, MNRAS, 251, 482
[31] Bremer, M. N. \& Johnstone, R. M. 1995, MNRAS, 277, 51
[32] Browne, I. W. A., Savage, A., \& Bolton, J. G. 1975, MNRAS, 173, 87P
[33] Bryan, G. L., Machacek, M., Anninos, P., \& Norman, M. L. 1999, ApJ, 517, 13
[34] Bunker, A. J., Marleau, F. R., \& Graham, J. R. 1998, AJ, 116, 2086
[35] Bunn, E. F. \& White, M. 1997, ApJ, 480, 6
[36] Burbidge, E. M. \& Kinman, T. D. 1966, ApJ, 145, 654
[37] Burbidge, E. M. 1970, ApJ, 160, 33
[38] Burles, S. \& Tytler, D. 1998a, ApJ, 499, 699
[39] Burles, S. \& Tytler, D. 1998b, ApJ, 507, 732
[40] Burstein, D. \& Heiles, C. 1982, AJ, 87, 1165
[41] Buson, L. M. \& Ulrich, M.-H. 1990, A\&A 240, 247
[42] Carswell, R. F., Coleman, G., Strittmatter, P. A., \& Williams, R. E. 1976, å, 53, 275
[43] Carswell, R. F., Whelan, J. A. J., Smith, M. G., Boksenberg, A., \& Tytler, D. 1982, MNRAS, 198, 91
[44] Carswell, R. F., Webb, J. K., Baldwin, J. A., \& Atwood, B. 1987, ApJ, 319, 709
[45] Caulet, A. 1989, ApJ, 340, 90
[46] Cen, R. 1992, ApJS, 78, 341
[47] Cen, R., Miralda-Escudé, J., Ostriker, J. P., \& Rauch, M. 1994, ApJ, 437, L9
[48] Chen, H.- W., Lanzetta, K. M., Webb, J. K., \& Barcons, X. 1998, ApJ, 498, 77
[49] Cheng, F. H., You, J. H., \& Yan, M. 1990, ApJ, 358, 18
[50] Cheng, F. H., Gaskell, C. M., \& Koratkar, A. P. 1991, ApJ, 370, 487
[51] Coles, P. \& Jones, B. 1991, MNRAS, 248, 1
[52] Cooke, A.J., Espey, B., \& Carswell, B. 1997, MNRAS, 284, 552
[53] Corbelli, E., Schneider, S. E, \& Salpeter, E. E. 1989, AJ, 97, 390
[54] Corbelli, E. \& Salpeter, E. E. 1993, ApJ419, 104
[55] Corbin, M. R. 1992, ApJ, 391, 577
[56] Corbin, M. R. \& Boroson, T. A. 1996. ApJ, 107, 69
[57] Corbin, M. R. 1997, ApJS, 113, 245
[58] Cowie, L. L., Songaila, A., Kim, T. -S., \& Hu, E. M. 1995, AJ, 109, 1522
[59] Cowie, L. L., \& Hu, E. M. 1998, AJ, 115, 1319
[60] Cristiani, S. \& Koehler, B. 1987, A\&AS, 68, 339
[61] Cristiani, S., D’Odorico, S., Fontana, A., Giallongo, E., \& Savaglio, S. 1995, MNRAS, 273, 1016
[62] Croft, R. A. C., Weinberg, D. H., Katz, N., \& Hernquist, L. 1997, ApJ, 488, 532
[63] Croft, R. A. C., Weinberg, D. H., Katz, N., \& Hernquist, L. 1998, ApJ, 495, 44
[64] Croft, R. A. C., Weinberg, D. H., Pettini, M., Hernquist, L., \& Katz, N. 1999, ApJ, 520, 1
[65] Davé, R., Hernquist, L., Katz, N., \& Weinberg, M. 1999, ApJ, 511, 521
[66] Davé, R. \& Tripp, T. M. 2001, ApJ, 553, 528
[67] Deharveng, J. -M., Faïsse, Milliard, B., \& Le Brun, V. 1997, A\&A, 325, 1259
[68] Devriendt, J. E. G., Sethi, S. K., Guideroni, B., \& Nath, B. B. 1998, MNRAS, 298, 708
[69] Djorgovski, S. G., Castro, S., Stern, D., \& Mahabal, A. A. 2001, ApJ, 560, 5L
[70] Dobrzycki, A. \& Bechtold, J. 1996, ApJ, 457, 102
[71] Dobrzycki, A., Engels, D., \& Hagen, H.-J. 1999, å, 349, L49
[72] Dobrzycki, A., Bechtold, J., Scott J., \& Morita, M. 2002, ApJ, in press (Paper IV)
[73] Donahue, M., Aldering, G., \& Stocke, J. T. 1995, ApJ, 450, L45
[74] Dove, J. B. \& Shull, J. M. 1994, ApJ, 423, 196
[75] Efron, B. 1982, The Jackknife, the Bootstrap, and Other Resampling Plans, (Philadelphia: Society for Industrial and Applied Mathematics)
[76] Eke, V. R., Cole, S., \& Frenk, C. S. 1996, MNRAS, 282, 263
[77] Ellingson, E., Yee, H. K. C., \& Green, R. F. 1991, ApJ, 371, 49
[78] Ellingson, E., Yee, H. K. C., Bechtold, J., \& Dobrzycki, A. 1994, AJ, 107, 1219
[79] Espey, B., Carswell, R. F., Bailey, J. A., Smith, M. G., \& Ward, M. J. 1989, ApJ, 342, 666
[80] Fabricant, D., Cheimets, P., Caldwell, N., \& Geary, J. 1998, PASP, 11079
[81] Falomo, R., Pesce, J. E., \& Treves, A. 1993, ApJ, 411, L63
[82] Fan, X., Narayanan, V. K., Strauss, M. A., White, R. L., Becker, R. H., Pentericci, L., Rix, H.-W. 2002, AJ, 123, 1247
[83] Fardal, M. A., Giroux, M. L. \& Shull, J. M. 1998, AJ, 115, 2206
[84] Fernández-Soto, A., Barcons, X., Carballo, R., \& Webb, J. K. 1995, MNRAS, 277, 235
[85] Foltz, C. B., Weymann, R. J., Peterson, B. M., Sun, L, Malkan, M. A., \& Chaffee, F. H. Jr. 1986, ApJ, 307, 504
[86] Foltz, C. B., Chaffee, F. H. Jr., Turnshek, D. A., Weymann, R. J., \& Anderson, S. F. 1987, AJ, 94, 1423
[87] Foltz, C. B., Chaffee, F. H. Jr., Hewitt, P. C., Weymann, R. J., Anderson, S. F., \& MacAlpine, G. M. 1989, AJ, 98, 1959.
[88] Forman, W. \& Jones, C. 1982, ARAA, 20, 547
[89] Francis, P. J. 1996, Pub. Ast. Soc. Aust., 13, 212
[90] Gallego, J. M., Zamorano, J., Aragón-Salamanca, A., \& Rego, M. 1995, ApJ, 455, L1
[91] Ganguly, R., Charlton, J., C., \& Eracleous, M. 2001, ApJ, 556, 7L
[92] Gaskell, C. M. 1982, ApJ, 263, 79
[93] Giallongo, E., Cristiani, S., Fontana, A., \& Trèvese, D. 1993, ApJ, 417, 137
[94] Giallongo, E., Cristiani, S., D'Odorico, S., Fontana, A., \& Savaglio, S. 1996, ApJ, 466, 46
[95] Giallongo, E., Cristiani, S., D’Odorico, S., \& Fontana, A. 2002, ApJ, 568, 9L
[96] Gnedin, N. 2002, MNRAS, submitted, (astro-ph/0110290)
[97] Green, R. F., Schmidt, M., \& Liebert, J. 1986, ApJS, 61, 305
[98] Green, P. J. 1996, ApJ, 467, 61
[99] Haardt, F. \& Madau, P. 1996, ApJ, 461, 20
[100] Haehnelt, M. G. \& Rees, M. J. 1993, MNRAS, 263, 168
[101] Haehnelt, M. G., Rauch, M., \& Steinmetz, M. 1996, MNRAS, 283, 1055
[102] Haehnelt, M. G., Madau, P., Kudritzki, R., \& Haardt, F. 2001, ApJ, 459, L151
[103] Hall, P., Ellingson, E., \& Green, R. F. 1997, AJ, 113, 1179
[104] Hamann, F., Zuo, L., \& Tytler, D. 1995, ApJ, 444, L69
[105] Hamann, F., Barlow, T. A., \& Junkkarinen, V. 1997, ApJ, 478, 87
[106] Hamann, F. W., Barlow, T. A., Chaffee, F. C., Foltz, C. B., \& Weymann, R. J. 2001, ApJ, 550, 142
[107] Heisler, J. \& Ostriker, J. 1988, ApJ, 332, 543
[108] Hernquist, L., Katz, N., Weinberg, D., \& Miralda- Escudé, J. 1996, ApJ, 457, L51
[109] Hewitt, A. \& Burbidge, G. 1987, ApJS, 63, 1
[110] Hewitt, A. \& Burbidge, G. 1993, ApJS, 87, 451
[111] Hook, I. M., M ${ }^{c}$ Mahon, R. G., Patnaik, A. R., Browne, I. W. A., Wilkinson, P. N., Irwin, M. J., \& Hazard, C. 1995, MNRAS, 273, L63
[112] Hook, I. M., Shaver, P. A., \& M ${ }^{c}$ Mahon, R. G. 1998, in The Young Universe, ed. S. D'Odorico, A. Fontana, \& E. Giallongo, (San Francisco: ASP), 17
[113] Hu, E. M., Kim, T. -S., Cowie, L. L., \& Songaila, A. 1995, AJ, 110, 1526
[114] Hu, E. M. \& M ${ }^{c}$ Mahon, R. G. 1996, Nature, 382, 231
[115] Hu, E. M., Cowie, L. L., \& M ${ }^{c}$ Mahon, R. G. 1998, ApJ, 502, L99
[116] Hu, E. M., M ${ }^{c}$ Mahon, R. G., \& Cowie, L. L. 1999, ApJ, 522, 9
[117] Hui, L. \& Gnedin, N. Y. 1997, MNRAS, 292, 27
[118] Hui, L., Gnedin, N. Y., \& Zhang, Y. 1997, ApJ, 486, 599
[119] Impey, C. D., Petry, C. E., \& Flint, K. P. 1999, ApJ, 524, 5361
[120] Irwin, M., M ${ }^{c}$ Mahon, R. G., \& Hazard, C. 1991, in Space Distribution of Quasars, ed. D. Crampton (San Francisco: ASP), 117
[121] Jannuzi, B. T., Bahcall, J. N., Bergeron, J., Boksenberg, A., Hartig, G., Kirhakos, S., Sargent, W. L. W., Savage, B. D., Schneider, D. P., Turnshek, D. A., Weymann, R. J., \& Wolfe, A. M. 1998, ApJS, 118, 1
[122] Jauncey, D. L., Wright, A. E., Peterson, B. A., \& Condon, J. J. 1978, ApJ, 219, L1
[123] Johnson, H. L. 1966, ARAA, 4, 193
[124] Junkkarinen, V., Hewitt, A., \& Burbidge, G. 1991, ApJS, 77,203
[125] Kennefick, J. D., Djorgovski, S. G., \& de Carvalho, R. R. 1995, AJ, 110, 2553
[126] Kim, T.- S., Hu, E. M., Cowie, L. L., Songaila, A. 1997, AJ, 114, 1
[127] Kim, T.- S., Cristiani, S., \& D'Odorico, S. 2001, A\&A, 373, 757
[128] Kinman, T. D. \& Burbidge, E. M. 1967, ApJ, 148, L59
[129] Kinney, A. L., Bohlin, R. C., Blades, J. C., \& York, D. G. 1991, ApJS, 75, 645
[130] Kirkman, D., Tytler, D., Burles, S., Lubin, D., \& O'Meara, J. M. 2000, ApJ, 529, 655
[131] Knezek, P. M. \& Bregman, J. N. 1998, ApJ, 115, 1737
[132] Koo, D. C. \& Kron, R. G. 1988, ApJ, 325, 92
[133] Koratkar, A. P., Kinney, A. L., \& Bohlin, R. C. 1992, ApJ, 400, 435
[134] Kriss, G. A., Shull, J. M., Oegerle, W., Zheng, W., Davidsen, A. F., Songaila, A., Tumlinson, J., Cowie, L. L., Deharveng, J.- M., Friedman, S. D., Giroux, M. L., Green, R. F., Hutchings, J. B., Jenkins, E. B., Kruk, J. W., Moos, H. W., Morton, D. C., Sembach, K. R., \& Tripp, T. M. 2001, Science, 293, 1112
[135] Kudritzki, R.-P., Méndez, R. H., Feldmeier, J. J., Ciardullo, R., Jacoby, G. H., Freeman, K. C., Arnaboldi, M., Capaccioli, M., Gerhard, O., Ford, H. C. 2000, ApJ, 536, 19
[136] Kuhn, O. 1996, PhD dissertation.
[137] Kulkarni, V. P. \& Fall, S. M. 1993, ApJ, 413, L63 (KF93)
[138] Kunth, D., Sargent, W. L. W., \& Kowal, C. 1981, å, 44, 229
[139] Kutyrev, A. S. \& Reynolds, R. J. 1989, ApJ, 344, L9
[140] Lanzetta, K. M., Turnshek, D. A., \& Wolfe, A. M. 1987, ApJ, 322, 739 (LTW87)
[141] Lanzetta, K. M. 1991, ApJ, 375, 1
[142] Lanzetta, K. M., Turnshek, D. A., \& Sandoval J. 1993, ApJS, 84, 109
[143] Lanzetta, K. M., Bowen, D. V., Tytler, D., Webb, J. K. 1995, ApJ, 442, 538
[144] Lanzetta, K. M., Wolfe, A. M., \& Turnshek, D. A. 1995, ApJ, 440, 435
[145] Lanzetta, K. M., Webb, J. K., \& Barcons, X. 1996, ApJ, 456, L17
[146] Laor, A., Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., Green, R. F., \& Hartig, G. F. 1994, ApJ, 420, 110
[147] Laor, A., Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., \& Green, R. F. 1995, ApJS, 99, 1
[148] Lawrence, C. R., Zucker, J. R., Readhead, A. C. S., Unwin, S. C., Pearson, T. J., Xu, W. 1996, ApJS, 107, 541
[149] Lilly, S. J., Tresse, L., Hammer, F., Crampton, D., \& Le Fèvre, O. 1995, ApJ, 455, 108
[150] Liske, J. \& Williger, G. M. 2001, MNRAS, 328, 653
[151] Lockman, F. J. \& Dickey, J. M. 1995, ADIL FL 01L (NCSA Astronomy Digital Image Library)
[152] Loeb, A. \& Eisenstein, D. J. 1995, ApJ, 448, 17L
[153] Lowenthal, J. D., Hogan, C. J., Leach, R. W. \& Schmidt, G. D. 1990, ApJ, 347, 3
[154] Lowenthal, J. D., Koo, D. C., Guzman, R., Gallego, J., Phillips, A. C., Faber, S. M., Vogt, N. P., Illingworth, G. D., \& Gronwall, C. 1997, ApJ, 481, 673
[155] Lesser, M. 1994, Proc. SPIE, 2198, 782
[156] Lu, L., Wolfe, A. M., \& Turnshek, D. A. 1991, ApJ, 367, 19 (LWT)
[157] Lu, L., Sargent, W. L. W., Womble, D. S., \& Takada-Hidai, M. 1996, ApJ, 472, 509
[158] Lynds, C. R., Hill, S. J., Heere, K., \& Stockton, A. 1966, ApJ, 144, 1244
[159] Lynds, R. \& Wills, D. 1968, ApJ, 153, L23
[160] Lynds, C. R. 1971, ApJ, 164, L73
[161] MacAlpine, G. M. \& Feldman, F. R. 1982, ApJ, 261, 412
[162] Madau, P. 1991, ApJ, 376, L33
[163] Madau, P. 1992, ApJ, 389, L1
[164] Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., \& Fruchter, A. 1996, MNRAS, 283, 1388
[165] Madau, P. \& Shull, J. M. 1996, ApJ, 457, 551
[166] Madau, P., Haardt, F., \& Rees, M. J. 1998, ApJ, 514, 648
[167] Maloney, P. 1993, ApJ, 414, 41
[168] Marshall, H. L. 1985, ApJ, 299, 109
[169] Martínez-González, E, González-Serrano, J. I., Cayón, L., Sanz, J. L., \& MartínMirones, J. M. 1995, A\&A, 303, 379
[170] M${ }^{c}$ Donald, P., Miralda-Escudé, J., Rauch, M., Sargent, W. L. W., Barlow, T. A., Cen, R., Ostriker, J. 2002, ApJ, 543, 1
[171] M Dowell, J. C., Canizares, C., Elvis, M., Lawrence, A., Markoff, S., Mathur, S., \& Wilkes, B. 1995, ApJ, 450, 585
[172] McIntosh, D. H., Rieke, M., Rix, H. -W., Foltz. C. B., \& Weymann, R. J. 1999a, ApJ, 514, 40
[173] Mc Intosh, D. H., Rix, H. -W., Rieke, M., Foltz. C. B. 1999b, ApJ, 517L, 73
[174] Meiksin, A. \& Madau, P. 1993, ApJ, 412, 34
[175] Miralda-Escudé, J. \& Ostriker, J. P. 1990, ApJ, 350, 1
[176] Miralda-Escudé, J. \& Rees, M. J. 1994, MNRAS, 266, 343
[177] Miralda-Escudé, J., Cen, R., Ostriker, J. P., Rauch, M., 1996, ApJ, 471, 582
[178] Miralda-Escudé, J., Haehnelt, M., \& Rees, M. J. 2000, ApJ, 530, 1
[179] Morris, S. L. \& Ward, M. J. 1988 MNRAS, 230, 639
[180] Morris, S. L., Weymann, R. J., Savage, B. D., \& Gilliland, R. L. 1991, ApJ, 377, L21
[181] Morton, D. C., York, D. G., \& Jenkins, E. B. 1988, ApJS, 68, 4491997
[182] Mulchaey, J. S. 2000, ARAA, 38, 289
[183] Murdoch, H. S., Hunstead, R. W., Pettini, M., \& Blades, J. C. 1986, ApJ, 309, 19 (MHPB)
[184] Nandy, K., Thompson, G. I., Jamar, C., Monfils, A., \& Wilson, R. 1975, å, 44, 195
[185] Nelson, B. O. \& Malkan, M. A. 1992, ApJS, 82, 447
[186] Netzer, H., Kazanas, D., Wills, B. J., Wills, D., Mingsheng, H., Brotherton, M.
S., Baldwin, J. A., Ferland, G. J., \& Browne, I. W. A. 1994, ApJ, 430, 191
[187] Nishihara, E., Yamashita, T., Yoshida, M., Watanbe, E., Okumura, S.-I., Mori, A., \& Iye, M. 1997, ApJ, 488, L27
[188] Oemler, A., Jr. \& Lynds, C. R. 1975, ApJ, 199, 558
[189] Ortiz-Gil, A., Lanzetta, K. M., Webb, J. K., Barcons, X., \& Fernández-Soto, A. 1999, ApJ, 523, 720
[190] Osmer, P. S., Porter, A. C., \& Green, R. F. 1994, ApJ, 436, 678
[191] Papovich, C., Norman, C. A., Bowen, D. V., Heckman, T., Savaglio, S., Koekemoer, A. M., \& Blades, J. C. 2000, ApJ, 531, 654
[192] Pascarelle, S. M., Windhorst, R. A., \& Keel, W. C. 1998, AJ, 116, 2659
[193] Pascarelle, S. M., Lanzetta, K. M., Chen, H. -W., \& Webb, J. K. 2001, ApJ, 560, 101
[194] Peebles, P. J. E. 1993, Principles of Physical Cosmology, (Princeton: Princeton University Press)
[195] Pei, Y. C., Fall, S. M., \& Bechtold, J. 1991, ApJ, 378, 6
[196] Pei, Y. 1995, ApJ, 438, 623
[197] Penton, S. V., Stocke, J. T., \& Shull, J. M. 2000a, ApJS, 130, 121
[198] Penton, S. V., Shull, J. M., \& Stocke, J. T. 2000b, ApJ, 544, 140
[199] Penton, S. V., Stocke, J. T., \& Shull, J. M. 2002, ApJ, 565, 720
[200] Perez, E., Penston, M. V., \& Moles, M. 1989, MNR.AS, 239, 55
[201] Press, W. H., Teukolsky, S. A., Vetterling, W. T., \& Flannery, B. P. 1992, Numerical Recipes in Fortran 77, The Art of Scientific Computing, Second Edition, Cambridge: Cambridge University Press
[202] Press, W. H., Rybicki, G. B., \& Schneider, D. P. 1993, ApJ, 414, 64
[203] Rauch, M., Miralda-Escudé, J., Sargent, W. L. W., Barlow, T., Weinberg, D.
H., Hernquist, L., Katz, N., Cen, R., Ostriker, J. P. 1997,ApJ, 489, 7
[204] Reimers, D., Köhler, S., Wisotzki, L., Groote, D., Rodriguez-Pascual, P., \& Wamsteker, W. 1997, å, 327, 890
[205] Reisenegger, A. \& Miralda-Escudé, J. 1995, ApJ, 449, 476
[206] de Robertis, M. 1985, ApJ, 289, 67
[207] Rhoads, J. E., Malhotra, S., Dey, A., Stern, D., Spinrad, H., Jannuzi, B. T. 2000, ApJ, 545, L85
[208] Sanduleak, N. \& Pesch,P. 1984, ApJS, 55, 517
[209] Sargent, W. L. S., Young, P. J., Boksenberg, A., Carswell, R. F., \& Whelan, J. A. J. 1979, ApJ, 230, 49
[210] Sargent, W. L. S., Young, P. J., Boksenberg, A., \& Tytler, D. 1980, ApJS, 42, 41
[211] Sargent, W. L. S., Young, P. J., \& Boksenberg, A. 1982, ApJ, 252, 54
[212] Sargent, W. L. S., Boksenberg, A. \& Steidel, C. C. 1988, ApJS, 68,539 (SBS88)
[213] Sargent, W. L. S., Steidel, C. C., \& Boksenberg, A. 1989, ApJS, 69, 703
[214] Savage, B. D., Lu, L., Bahcall, J. N., Bergeron, J., Boksenberg, A., Hartig, G., Jannuzi, B. T., Kirhakos, S., Lockman, F., Sargent, W. L. W., Schneider, D. P., Turnshek, D., Weymann, R. J., \& Wolfe, A. M. 1993, ApJ, 413, 116
[215] Savaglio, S., Cristiani, S., D'Odorico, S., Fontana, A., Giallongo, E., \& Molaro, P. 1997, A\&A, 318, 347
[216] Schaye, J., Theuns, T., Leonard, A., \& Efstathiou, G. 1999, MNRAS, 310, 57
[217] Schmidt, M. 1968, AJ, 73, 117S
[218] Schmidt, M. \& Olsen, E. T. 1968, AJ, 73, 5117
[219] Schmidt, M. 1977, ApJ, 217, 358
[220] Schmidt, M., Schneider, D. P., \& Gunn, J. E. 1986, ApJ, 310, 518
[221] Schmidt, M., Schneider, D. P., \& Gunn, J. E. 1991, in Space Distribution of Quasars, ed. D. Crampton (San Francisco: ASP), 109
[222] Scott, J., Bechtold, J., \& Dobrzycki, A. 2000, ApJS, 130, 37 (Paper I)
[223] Scott, J., Bechtold, J., Dobrzycki, A. \& Kulkarni, V. 2000, ApJS, 130, 67 (Paper II)
[224] Scott, J., Bechtold, J., Morita, M., Dobrzycki, A. \& Kulkarni, V. 2002, ApJ, in press (Paper V)
[225] Seaton, M. J. 1979 MNRAS, 187, 73P
[226] di Serego-Alighieri, S., Danziger, I. J., Morganti, R., \& Tadhunter, C. N. 1994, MNRAS, 269, 998
[227] Shaver, P. A., Wall, J. V., Kellermann, K. I., Jackson, C. A., \& Hawkins, M. R. S. 1996, Nature, 384, 439
[228] Shull, J. M., Stocke, J. T., \& Penton, S. V. 1996, AJ, 111, 72
[229] Shull, J. M., Penton, S. V., \& Stocke, J. T. 1999, PASA, 16, 95
[230] Shull, J. M., Roberts, D., Giroux, M. L., Penton, S. V., Fardal, M. A. 1999, AJ, 118, 1450
[231] Smith, H. E., Burbidge, E. M., Baldwin, J. A., Tohline, J. E., Wampler, E. J., Hazard, C., \& Murdoch, H. S. 1977, ApJ, 215, 427
[232] Smith, R. J., Boyle, B. J., \& Maddox, S. J. 2000, MNRAS, 313, 252
[233] Songaila, A., Bryant, W., \& Cowie, L. L. 1989, ApJ, 345, L71
[234] Songaila, A. \& Cowie, L. L. 1996, AJ, 112, 335
[235] Songaila, A. 1998, AJ, 115, 2184
[236] Songaila, A. \& Cowie L. L. 2002, AJ, 123, 2183
[237] Srianand, R. \& Khare, P. 1996, MNRAS, 280, 767
[238] Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R. A., Heiles, C., \& Hurwitz, M. 1992, ApJS, 79, 77
[239] Steidel, C. 1990, ApJS, 74, 37
[240] Steidel, C. \& Sargent, W. L. S. 1991, ApJ, 382, 433
[241] Steidel, C. \& Sargent, W. L. S. 1992, ApJS, 80, 1 (SS92)
[242] Steidel, C. C., Giavalisco, M., Dickinson, M., Adelberger, K. L. 1996a, AJ, 112, 352
[243] Steidel, C. C., Giavalisco, M., Pettini, M., Dickinson, M., \& Adeleberger, K. L. 1996b, ApJ, 462, L17
[244] Steidel, C. C., Adelberger, K. L., Shapley, A. E., Pettini, M., Dickinson, M., \& Giavalisco, M. 2000, ApJ, 532, 170
[245] Steidel, C. C., Pettini, M., \& Adelberger, K. L. 2001, ApJ, 546, 665
[246] Stengler-Larrea, E. A., Boksenberg, A., Steidel, C. C., Sargent, W. L. W., Bahcall, J. N., Bergeron, J., Hartig, G., Jannuzi, B. T., Kirhakos, S., Savage, B. D., Schneider, D. P., Turnshek, D. A., \& Weymann, R. J. 1995, ApJ, 444, 64
[247] Stickel, M. \& Kühr, H. 1993, A\&AS, 100, 395
[248] Stocke, J. T., Case, J., Donahue, M., Shull, J. M., \& Snow, T. P. 1991, ApJ, 374, 72
[249] Stocke, J. T., Shull, J. M., Penton, S., Donahue, M., \& Carilli, C. 1995, ApJ, 451, 24
[250] Stockton, A. 1982, ApJ, 257, 33
[251] Stockton, A. \& MacKenty, J. W. 1987, ApJ, 316, 584
[252] Storrie-Lombardi, L. J., M ${ }^{c}$ Mahon, R. G., Irwin, M. J., \& Hazard, C. 1994, ApJ, 427, L13
[253] Storrie-Lombardi, L. J. 1995, in Proc. of the ESO Workshop on QSO Absorption Lines, ed. G. Meylan (Berlin: Springer), 47
[254] Sugiyama, N. 1995, ApJS, 100, 281
[255] Telfer, R. C., Zheng, W., Kriss, G. A., \& Davidsen, A. F. 2001, ApJ, in press (astro-ph/0109531)
[256] Theuns, T., Leonard, A., \& Efstathiou, G., Pearce, F. R., \& Thomas, P. A. 1998a, MNRAS, 301, 478
[257] Theuns, T., Leonard, A., Efstathiou, G. 1998, MNRAS, 297, L49
[258] Thommes, E., Meisenheimer, K., Fockenbrock, R., Hippelein, H., Roeser, H.-J., \& Beckwith, S. 1998, MNRAS, 293, L6
[259] Thompson, D. J., Djorgovsky, S., \& Weir, W. N. 1989 PASP, 101, 1065
[260] Tufte, S. L., Reynolds, R. J., \& Haffner, L. M. 1998, ApJ, 504, 773
[261] Tumlinson, J., Giroux, M. L., Shull, J. M., \& Stocke, J. T. 1999, AJ, 118, 2148
[262] Tytler, D. 1987, ApJ, 321, 69
[263] Tytler, D., Boksenberg, A., Sargent, W. L. W., Young, P., \& Kunth, D. 1987, ApJS, 64, 667
[264] Tytler, D. \& Fan, X. -M. 1992, ApJS, 79, 1
[265] Tytler, D., Fan, X. -M., Junkkarinen, V. T., \& Cohen, R. D. 1993, AJ, 106, 426 (T93)
[266] Tytler, D. \& Fan, X. -M. 1994, ApJ, 424, L87
[267] Ulrich, M.- H. 1976, ApJ, 206, 364
[268] Uomoto, A. 1984, ApJ, 284, 497
[269] van Gorkom, J. H. 1993, in The Environment and Evolution of Galaxies, ed. J. M Shull \& H. A. Thronson (Dordrecht:Kluwer), 343
[270] Viel, M., Matarrese, S., Mo, H. J., Theuns, T., \& Haehnelt, M. G. 2002, MNRAS, submitted (astro-ph/203418)
[271] Vogel, S. N., Weymann, R., Rauch, M., \& Hamilton, T. 1995, ApJ, 441, 162
[272] Warren, S. J., Hewett, P. C., \& Osmer, P. S. 1994, ApJ, 421, 412
[273] Weinberg, D. H., Miralda-Escudé, J., Hernquist, L., \& Katz, N. 1997, ApJ, 490, 564
[274] Weinberg, D. H., Croft, R. A. C., Hernquist, L., Katz, N., \& Pettini, M. 1998, ApJ, 522, 563
[275] Weymann, R. J., Williams, R. E., Peterson, B. M., \& Turnshek, D. A. 1979, ApJ, 234, 33
[276] Weymann, R. J., Carswell, R. F., \& Smith, M. G. 1981, ARAA, 19, 41
[277] Weymann, R. J., Jannuzi, B. T., Lu, L., Bahcall, J. N., Bergeron, J., Boksenberg, A., Hartig, G., Kirhakos, S., Sargent, W. L. W., Savage, B. D., Schneider, D. P., Turnshek, D. A., \& Wolfe, A. 1998, ApJ, 506, 1
[278] Weymann, R. J., Vogel, S. N., Veilleux, S., \& Epps, H. 2001, ApJ, 561, 559
[279] Wilkes, B. J. 1986, MNRAS, 218, 331
[280] Williger, G. M., Baldwin, J. A., Carswell, R. F., Cooke, A. J., Hazard, C., Irwin, M. J., Mc Mahon, R. G., \& Storrie-Lombardi, L. J. 1994, ApJ, 428, 574
[281] Wills, D. \& Wills, B. J. 1976, ApJS, 31, 143
[282] Wills, B. J. \& Wills, D. 1979, ApJS, 41, 689
[283] Wold, M., Lacy, M., Lilje, P. B., \& Serjeant, S. 2000, MNRAS, 316, 267
[284] Wolfe, A. M., Turnshek, D. A., Smith, H. E., Cohen, R. D. 1986, ApJS, 61, 249 (W86)
[285] Wolfe, A. M., Lanzetta, K. M., Foltz, C. B., \& Chaffee, F. H. 1995, ApJ, 454, 698
[286] Yates, M. G., Miller, L., \& Peacock, J. A. 1989, MNRAS, 240, 129
[287] Yee, H. K. C. \& Ellingson, E. 1993, ApJ, 411, 43
[288] Yee, H. K. C. 1987, AJ, 94, 1461
[289] Yee, H. K. C. \& Green R. F. 1987, AJ, 94, 618
[290] Yee, H. K. C. \& Green R. F. 1984, ApJ, 280, 79
[291] York, D. G., Yanny, B., Crotts, A., Carilli, C., Garrison, E., \& Matheson, L. 1991, MNRAS, 250, 24
[292] Young, P., Sargent, W. L. S., Boksenberg, A., Carswell, R. F., \& Whelan, J. A. J. 1979, ApJ, 228, 891
[293] Young, P., Sargent, W. L. S., \& Boksenberg, A. 1982a, ApJ, 252, 10
[294] Young, P., Sargent, W. L. S., \& Boksenberg, A. 1982b, ApJS, 48,455 (YSB82)
[295] Zhang, Y., Anninos, P., \& Norman, M. L. 1995, ApJ, 453, L57
[296] Zhang, Y., Meiksin, A., Anninos, P., \& Norman, M. L. 1998, ApJ, 495, 63
[297] Zheng, W. \& Sulentic, J. W. 1990, ApJ, 350, 512
[298] Zheng, W. \& Malkan, M. A. 1993, ApJ, 415, 517
[299] Zheng, W., Kriss, G. A., Davidsen, A. F., Lee, G., Code, A. D., Bjorkman, K. S., Smith, P. S., Weistrop, D., Malkan, M. A., Baganoff, F. K., \& Peterson, B. M. 1995, ApJ, 444, 632
[300] Zheng, W., Kriss, G. A., Telfer, R. C., Grimes, J. P., \& Davidsen, A. F. 1997, ApJ, 474, 469
[301] Zotov, N. 1985, ApJ, 295, 94
[302] Zuo, L. \& Lu, L. 1993, ApJ, 418, 601


[^0]:    ${ }^{1}$ Note that Scott et al. (2000b) found deficits within $1.5 h^{-1} \mathrm{Mpc}$ of $3.6 \sigma$ for low luminosity objects and $4.6 \sigma$ for high luminosity objects using a standard CDM cosmology

[^1]:    ${ }^{2}$ The observed HI column density distribution of Ly- $\alpha$ forest absorbers is $d V / d N_{\mathrm{HI}} \propto N_{\mathrm{HI}}^{-3}$

