HIGH-RESOLUTION SPECTROSCOPY FROM 3050 TO 10000 Å OF THE HUBBLE DEEP FIELD SOUTH QSO J2233—606 WITH UVES AT THE ESO VERY LARGE TELESCOPE

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ABSTRACT

We report on high-resolution observations (R \approx 45,000) of the Hubble Deep Field South QSO J2233—606 obtained with the VLT UV-Visual Echelle Spectrograph. We present spectral data for the wavelength region 3050 Å < \lambda < 10000 Å. The signal-to-noise ratio of the final spectrum is about 50 per resolution element at 4000 Å, 90 at 5000 Å, 80 at 6000 Å, and 40 at 8000 Å. Redshifts, column densities, and Doppler widths of the absorption features have been determined with Voigt profile fitting. A total of 621 lines have been measured. In particular, 270 Ly\textsc{a} lines, 41 Ly\textsc{b} lines, and 24 systems containing metal lines have been identified. Together with other data in the literature, the present spectrum confirms that the evolution of the number density of Ly\textsc{a} lines with log N(H\textsc{i}) > 14 has an upturn at \( z \approx 1.4–1.6 \).

Key words: cosmology: observations — quasars: absorption lines — quasars: individual (J2233—606)

1. INTRODUCTION

Starting on 1998 September 28 and for 2 weeks, the Hubble Space Telescope (HST) aimed at the same narrow slice of sky in the constellation Tucana. The observing strategy of the Hubble Deep Field South (HDF-S; Williams et al. 2000) differs from its northern analog in several respects. The Space Telescope Imaging Spectrograph (STIS) field was centered on a relatively bright (B \approx 17.5) quasar at intermediate redshift (J2233—606, \( z_{\text{em}} = 2.238 \)). The installation of STIS and and the Near-Infrared Camera and Multi-Object Spectrometer on HST in 1997 February has enabled parallel observations with three cameras. In this way, the HDF-S data set includes deep Wide Field Planetary Camera 2 imaging (Casertano et al. 2000), UV-visible imaging (Gardner et al. 2000) and spectroscopy (Savaglio et al. 1999), deep near-infrared imaging (Fruchter et al. 2000), and wider area flanking-field observations (Lucas et al. 2000). Ground-based observations have been carried out at ESO with the Very Large Telescope and New Technology Telescope in the framework of the ESO HDF-South Project.\(^3\) The simultaneous availability of deep imaging and wide spectroscopic coverage at medium to high resolution makes the HDF-S a unique field to study the relationship between galaxies and absorbers, the quasar environment, and the abundance pattern of metal absorption systems.

Spectroscopic observations of J2233—606 have already been reported by Savaglio (1998, hereafter S98), Sealey et al. (1998), Outram et al. (1999, hereafter O99), and Savaglio et al. (1999). The relationship between the low-redshift (z < 1) galaxies lying within 1’ of the QSO and the absorption systems is described by Tresse et al. (1999), who also found another QSO in the field at an angular separation of 44’’.5 from the HDF-S QSO, with \( z_{\text{em}} = 1.336 \).

In this paper, we present high-resolution spectroscopy (R \approx 45,000) carried out with the VLT UV-Visual Echelle Spectrograph (UVES; Dekker, D’Odorico, & Kaufer 2000). These new data are unique in terms of signal-to-noise ratio and spectral range (3050–10000 Å) and ideally match the HST STIS observations obtained in the interval 2275–3118 Å with an FWHM resolution of 10 km s\(^{-1}\) (Savaglio et al. 1999). In § 2, the observations and data reduction are described. Section 3 deals with the process of identification of the absorption lines and their fitting through \( \chi^2 \) minimization of Voigt profiles. In § 4, the general properties of the Ly\textsc{a} forest are discussed, while § 5 describes the 24 identified metal systems.

2. OBSERVATIONS

The UVES observation of J2233—606 were carried out during the commissioning of the instrument in 1999 October. Details are given in Table 1. Two setups were used, the first (dichroic 1) covering simultaneously the 3050–3875 and 4795–6815 Å ranges in the blue and red arms, respectively, and the second (dichroic 2) covering simultaneously the 3760–5004 and 6725–10000 Å ranges in the blue and red arms, respectively.

The data have been reduced in the new UVES context available in the 99NOV version of MIDAS, the ESO data reduction system. For the wavelength calibration, thorium lamp spectra have been used. Wavelengths were then corrected to vacuum heliocentric values.

The final combined spectrum has been rebinned to a constant pixel size of 0.05 Å and covers the wavelength range 3050–10000 Å. The resolution, as measured from the thorium lines of the calibration spectra, extracted and treated in the same way as the QSO’s spectra, is R \approx 45,000. The signal-to-noise ratio of the final spectrum is about 50 per resolution element at 4000 Å, 90 at 5000 Å, 80 at 6000 Å, and 40 at 8000 Å.

The continuum level was established by selecting regions apparently free of absorptions and then fitting a cubic spline with a large smoothness parameter. The normalized spectra

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1 Based on material collected with the ESO Very Large Telescope.
2 On leave from the Departimento di Astronomia, Università di Padova.
3 See http://www.eso.org/paranal/sw/svhdfs.html.
were then spliced together to form a total spectrum. A section of the normalized spectrum from 3100 to 4300 Å is shown in Figure 1. The full spectrum is available in the form of FITS tables.\(^4\)

### 3. LINE IDENTIFICATION AND PROFILE FITTING

The MIDAS package FITLYMAN (Fontana & Ballester 1995) has been used to measure the parameters of the absorption lines. Line fitting through \(\chi^2\) minimization of Voigt profiles has been carried out in order to determine the redshifts, column densities, and Doppler widths of the identified features. When possible, we based our fit on the components found for multiple ions at the same redshift. The absorption-line parameter fits are presented in Table 2. Heavy-element systems are identified, in general, by the presence of the C\ IV and/or Mg\ II doublets. The spectral separation and intensity ratio between the lines of the doublet allow a firm identification. Subsequently, the strongest ions commonly observed in quasar spectra are searched for at the same redshift.

The atomic parameters for the absorption lines observed in QSO spectra have been taken from Morton (1991) and Verner, Barthel, & Tytler (1994). All the lines not identified as metals in the Ly\(\alpha\) forest are fitted as H\ I Ly\(\alpha\) and Ly\(\beta\).

If a strong ion is not detected in the spectrum, we report only an upper limit to the column density. The estimate is based on the fact that there is a linear relation between equivalent width and column density for weak lines (because they lie on the linear part of the curve of growth). First the equivalent width limit for that region is computed, and the corresponding column density is given by

\[
N_{\text{lim}}(\text{cm}^{-2}) \approx 1.13 \times 10^{20} \frac{w_{\text{lim}}(\text{Å})}{(\lambda_{\text{rest}}(\text{Å})/f_{\text{osc}})} .
\]

### 4. THE Ly\(\alpha\) FOREST

A total of 186 Ly\(\alpha\) lines are observed in the interval 3321.3–3885 Å, i.e., between the onset of the Ly\(\beta\) forest and the range affected by the proximity effect. The H\ I column density distribution for \(13 < \log N(\text{H} \ I) < 17.5\) is consistent with a power-law distribution with slope \(-1.41 \pm 0.05,\)

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\(^4\)At URL http://www.stecf.org/hstprogrammes/J22/J22.html.

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**Fig. 1.—**Normalized spectrum of J2233—606, plotted against vacuum heliocentric wavelength (Å). Each panel contains a strip of 100 Å with the wavelength increasing from the top to the bottom. The 1σ error level is also shown.
slightly flatter but not significantly different from the canonical value observed at higher redshift (Giallongo et al. 1996). The Doppler parameter distribution peaks between 20 and 25 km s\(^{-1}\), with a lower cutoff at 15 km s\(^{-1}\) for lines with log N(H \(\text{I}\)) > 14. Figure 2 shows the number density of Ly\(\alpha\) lines with log N(H \(\text{I}\)) > 14 observed in the spectrum of J2233—606. At a median redshift \((z) = 1.96 \pm 0.23\) we observe 33 such lines, 14 of which are associated with metal systems (see below). The corresponding \(dn/dz\) is 71 \pm 12 including metal systems and 41 \pm 9 excluding metal systems. The previous estimate of \(dn/dz\) in J2233—606 by Savaglio et al. (1999) is in good agreement with the present result. The comparison with data in the literature from other sight lines provides a consistent picture of the evolution of the density of Ly\(\alpha\) absorbers with redshift. In particular, the measurement derived from the spectrum of J2233—606 is remarkably close to the HST point at \((z) = 1.6\) by Weymann et al. (1998), which is based on 19 lines observed in the spectrum of the QSO UM 18. Figure 2 suggests that a sharp upturn in the density of Ly\(\alpha\) lines with log N(H \(\text{I}\)) > 14 takes place at a redshift \(z = 1.4–1.6\).

The density of Ly\(\alpha\) lines in J2233—606 not associated with metal systems (see next section) is also shown in Figure 2. The agreement with the corresponding data of Giallongo et al. (1996) is very good.\(^5\)

5. METAL SYSTEMS

In general, we consider a group of absorption lines due to the same ion as an individual metal system when the components are blended or not separated by more than a few tens of kilometers per second.

The strongest systems in the spectrum of J2233—606 were already detected by O99 and by S98. We started from their detections and looked for weaker components and more ions belonging to the same systems. Besides, we found four new Mg \(\text{II}\) doublets, seven new C \(\text{IV}\) doublets, and a new associated system showing C \(\text{IV}\) and N \(\text{V}\) absorptions.

In the following, we list the systems and give a short description of their main features. The quoted redshift is that of the strongest component or the average redshift in the case of complex systems (i.e., more than three components). All the metal systems are listed in Table 3.

\(^5\) The definition of “Ly\(\alpha\) line not associated with metal systems” is dependent on the data quality and is therefore not rigorous.

### Table 2

**Absorption-Line Parameter List**

| ID     | \(\lambda_{\text{cen}}\) (Å) | \(\lambda_{\text{obs}}\) (Å) | \(\sigma_{b}\) (Å) | Redshift | log N | \(\sigma_{\log N}\) | \(b\) (km s\(^{-1}\)) | \(\sigma_{b}\) (km s\(^{-1}\)) |
|--------|----------------|----------------|----------------|-----------|-------|----------------|----------------|----------------|
| H \(\text{I}\) | 1025.72 | 3088.793 | 0.005 | 2.0113347 | 13.85 | 0.01 | 26.7 | 0.7 |
| C \(\text{II}\) | 1334.53 | 3098.358 | 0.003 | 1.3216810 | 12.7 | 0.5 | 2.7 | 0.6 |
| C \(\text{II}\) | 1334.53 | 3098.468 | 0.007 | 1.3217632 | 12.9 | 0.3 | 5 | 1 |
| H \(\alpha\) | 1025.72 | 3102.299 | 0.008 | 2.0245020 | 14.08 | 0.04 | 22.2 | 0.9 |
| H \(\alpha\) | 1215.67 | 3107.89 | 0.05 | 1.5565236 | 13.89 | 0.05 | 54 | 5 |

**Note.**—Asterisks mark the H \(\alpha\) lines belonging to metal systems, while “(f)” stands for “fixed” and indicates that the line has been fitted by imposing the redshift, the Doppler parameter value, or both. Table 2 is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

### 5.1. Intervening Systems

5.1.1. **System at \(z_{\text{abs}} = -0.00002\)**

Strong Na \(\text{I} \lambda 5891, 5897\) is seen from the interstellar medium of the Galaxy.

5.1.2. **System at \(z_{\text{abs}} = 0.0002\)**

The complex Ca \(\text{II} \lambda 3934, 3969\) at this redshift was already observed by O99. We detected two more, weaker components. The 3969 Å line is blended with the N \(\text{v} \lambda 1238\) feature at \(z_{\text{abs}} = 2.206\).

5.1.3. **System at \(z_{\text{abs}} = 0.41426\)**

A single Mg \(\text{II} \lambda 2796, 2803\) doublet occurs at this redshift (O99). The fit with one component yields a relatively poor result, since the equivalent width ratio of the first line, Mg \(\text{II} \lambda 2796\), relative to the Mg \(\text{II} \lambda 2803\) line is lower than expected. A fit with a double structure does not yield a better result.

Tresse et al. (1999) observed three galaxies at \(z \sim 0.4147\) in the 1' field around the quasar. They claim that another object, closer to the quasar and belonging to the same overdensity of galaxies, could be responsible for this absorption system.

![Figure 2](image-url)

**Fig. 2.**—Number density evolution of the Ly\(\alpha\) clouds with log N(H \(\text{I}\)) > 14 from \(z = 0\) to \(z = 4\). Filled symbols are for samples that include metal systems, open symbols for samples that do not. The low-redshift line is the fit\(dn/dz \propto (1+z)^{0.18}\) derived from a sample of Ly\(\alpha\) absorbers with equivalent width\( EW \gtrsim 0.24\) Å (Weymann et al. 1998), which corresponds to log N(H \(\text{I}\)) > 14 for \(b \sim 26\) km s\(^{-1}\).
absorption likely associated with this galaxy is seen in the system with three components, spanning sight by Tresse et al. (1999). The UVES spectrum shows a doublet at this slightly lower absorption redshift, seen in the Lyman series; the fit of the Lyman limit in the STIS spectrum gives $N(H\,I) \sim 10^{16.6} \text{ cm}^{-2}$.

The UVES spectrum shows the associated Mg II doublet, with the strongest component at $z_{\text{abs}} = 0.57017$. We fitted the system with three components, spanning $\sim 86 \text{ km s}^{-1}$.

5.1.5. System at $z_{\text{abs}} = 0.58008$

This new, two-component Mg II doublet, seen in the UVES spectrum, falls at the redshift of another galaxy found in the field by Tresse et al. (1999) at an impact parameter $\sim 112 \text{ km s}^{-1}$ kpc from the quasar line of sight.

5.1.6. System at $z_{\text{abs}} = 0.64498$

A galaxy at a redshift $z = 0.6465$ was observed at an impact parameter $\sim 220 \text{ km s}^{-1}$ kpc from the quasar line of sight by Tresse et al. (1999). The UVES spectrum shows a single Mg II doublet at this slightly lower absorption redshift.

5.1.7. System at $z_{\text{abs}} = 0.75313$

A new Mg II doublet was found at this redshift in the UVES spectrum.

### Table 3

| Redshift* | $\log(N(H\,I))$ | $\log(N(\text{Si IV}))$ | $\log(N(\text{C IV}))$ | $\log(N(\text{Mg II}))$ | No.* |
|-----------|-----------------|-----------------|-----------------|-----------------|------|
| $-0.000002$ | ... | ... | ... | ... | 1 |
| $0.0002$ | ... | ... | ... | ... | 4 |
| $0.41426$ | ... | ... | ... | $12.79$ | 1 |
| $0.57017$ | ... | ... | ... | $12.55$ | 3 |
| $0.58008$ | ... | ... | ... | $12.60$ | 2 |
| $0.64498$ | ... | ... | ... | $12.34$ | 1 |
| $0.75313$ | ... | ... | ... | $11.27$ | 1 |
| $1.09169$ | ... | ... | $13.53$ | $<11.7$ | 1 |
| $1.32153$ | ... | $13.25$ | $14.74$ | $12.24$ | 3 |
| $1.3368$ | ... | ... | $13.59$ | $11.96$ | 4 |
| $1.4831$ | ... | Blend | $13.89$ | $<11.6$ | 5 |
| $1.55635$ | ... | $13.89$ | $12.19$ | $<11.7$ | 1 |
| $1.59055$ | ... | $14.1$ | $<12.1$ | $13.56$ | 2 |
| $1.73165$ | ... | $14.10$ | $<12$ | $12.53$ | 1 |
| $1.78618$ | ... | $15.54$ | $12.89$ | $14.03$ | 3 |
| $1.81565$ | ... | $15.15$ | $<11.8$ | $12.91$ | 2 |
| $1.8693$ | ... | $15.92$ | $13.65$ | $14.60$ | 17 |
| $1.92599$ | ... | $17.3$ | $12.87$ | $13.59$ | 3 |
| $1.9422$ | ... | $16.33$ | $13.76$ | $14.60$ | 9 |
| $2.07729$ | ... | $15.64$ | $<12$ | $13.24$ | 2 |
| $2.11287$ | ... | $14.91$ | $<12$ | $12.7$ | 2 |
| $2.19819$ | ... | $13.64$ | $<12.1$ | $13.95$ | 3 |
| $2.20106$ | ... | $<12$ | $<12.1$ | $13$ | 2 |
| $2.2064$ | ... | $13.55$ | $<12$ | $14.26$ | 4 |

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* See definition in § 5.
** Logarithmic total column density.
*** Number of components fitted to the C IV absorption feature or to the Mg II absorption feature, if C IV is not observed.
**** Galactic Na I $\lambda\lambda 5891, 5897$.
***** Galactic Ca II $\lambda\lambda 3934, 3969$.
****** Associated systems.

5.1.8. System at $z_{\text{abs}} = 1.09169$

This is a new C IV $\lambda\lambda 1548, 1550$ system, fitted with two components.

5.1.9. System at $z_{\text{abs}} = 1.32153$

A new C IV doublet in the Ly$\alpha$ forest is observed at this redshift. There is one, clear, unblended component in both 1548 and 1550 Å lines. On the basis of the absence of the corresponding Ly$\beta$ line, we assumed that the whole feature is C IV $\lambda\lambda 1548$ and not H I Ly$\alpha$, and we fitted it with three components. We tentatively identified a feature showing the same velocity profile as C IV to be the Si IV $\lambda 1393$ absorption, while the corresponding Si IV 1402 Å line is blended with a strong H I Ly$\alpha$ complex. At a slightly higher redshift, a weak Mg II doublet has been observed, showing two stronger components and a flat one in Mg II $\lambda 2796$. At this redshift, also the lines Fe II $\lambda 2600$, Fe II $\lambda 2382$, C II $\lambda 1334$, Si II $\lambda 1526$ have been detected.

5.1.10. System at $z_{\text{abs}} = 1.3368$

Tresse et al. (1999) found another quasar in the field at a redshift $z \approx 1.3360$ and at an angular separation of 44'5 from the current object. They measured the H I column density from the Ly$\alpha$ and Ly$\beta$ absorption lines, observed in the high-resolution portion of the STIS spectrum. A one-component fit gives $N(H\,I) \sim 5 \times 10^{15} \text{ cm}^{-2}$ and a Doppler parameter $b \sim 50 \text{ km s}^{-1}$.

The UVES spectrum reveals a complex C IV doublet absorption at a slightly higher redshift, covering almost 200 km s$^{-1}$. Even though the system falls in the Ly$\alpha$ forest, the identification is quite reliable because of the characteristic
profile. The C IV λ1548 feature is blended with the possible Si II λ1260 of the system at \( z_{\text{abs}} = 1.87 \), while the reddest component of C IV λ1550 could be blended with the possible N v λ1238 at \( z_{\text{abs}} = 1.926 \). We also detected a weak, less extended Mg II doublet on the lower redshift side of the C IV absorption and a weak, possible Si IV doublet corresponding to the highest redshift component of C IV. Finally, a fit of the H I Ly\( \alpha \) line in the STIS spectrum with the same velocity structure as the C IV system gives a total column density of \( N(\text{H I}) \approx 3.7 \times 10^{16} \text{ cm}^{-2} \).

5.1.11. System at \( z_{\text{abs}} = 1.4831 \)

A complex of five C IV λ1548, 1550 doublets, spanning 75 km s\(^{-1}\), is seen within the Ly\( \alpha \) forest. The identification (by O99) is firm, thanks to the distinctive pattern of the absorption. No other associated metal line is identified.

5.1.12. System at \( z_{\text{abs}} = 1.5034 \)

We cannot confirm the existence of this system tentatively identified by S98. The 3 \( \sigma \) column density limit on the Mg II λ2796 absorption is \( N(\text{Mg II}) \leq 4 \times 10^{11} \text{ cm}^{-2} \). Other strong low-ionization lines such as Mg I λ2852 and Fe II λ2382 are not observed, and there is not the expected strong Ly\( \alpha \) line in the STIS spectrum.

5.1.13. System at \( z_{\text{abs}} = 1.55635 \)

A new, possible, weak C IV doublet has been found at this redshift. The corresponding Ly\( \alpha \) line has an unexpectedly low column density, \( N(\text{H I}) \approx 8 \times 10^{13} \text{ cm}^{-2} \).

5.1.14. System at \( z_{\text{abs}} = 1.59055 \)

This two-component C IV doublet, separated by 9 km s\(^{-1}\), was already observed by O99. No Si IV absorption was detected for this system; \( N(\text{Si IV}) \lesssim 1.2 \times 10^{12} \text{ cm}^{-2} \) is a 3 \( \sigma \) upper limit on the column density. The UVES spectrum shows a possible N v doublet feature at the redshift of the stronger component. We fitted the corresponding Ly\( \alpha \) line with the same components as the C IV doublet.

5.1.15. System at \( z_{\text{abs}} = 1.73165 \)

A possible, weak C IV doublet has been found in the UVES spectrum, coinciding with an \( N(\text{H I}) \approx 1.2 \times 10^{14} \text{ cm}^{-2} \) Ly\( \alpha \) line.

5.1.16. System at \( z_{\text{abs}} = 1.78618 \)

This system was already reported by Sealey, Drinkwater, & Webb (1998). C IV has been observed by S98 and by O99. The UVES spectrum does not confirm the presence of Mg I λ2852 tentatively detected by S98. The 3 \( \sigma \) limit on this ion is \( N(\text{Mg I}) \lesssim 2 \times 10^{11} \text{ cm}^{-2} \). On the other hand, Si IV λ1393, 1402 is visible in the Ly\( \alpha \) forest, although there is clear blending with H I lines. The corresponding H I Ly\( \alpha \) line was fitted with two components for a total column density \( N(\text{H I}) \approx 3.5 \times 10^{15} \text{ cm}^{-2} \).

5.1.17. System at \( z_{\text{abs}} = 1.81565 \)

At this redshift, a possible, extremely weak C IV doublet absorption is observed; the 1550 Å line is barely visible. We fitted the feature with two components, together with the corresponding H I Ly\( \alpha \) line, whose total column density is \( N(\text{H I}) \approx 1.4 \times 10^{15} \text{ cm}^{-2} \).

5.1.18. System at \( z_{\text{abs}} = 1.8693 \)

This complex heavy-element system was already reported by O99 and by S98. The UVES spectrum, besides showing the Si IV λ1393, 1402 doublet, partially resolves the C IV λλ1548, 1550 features and shows the associated absorption by Si III λ1206. The 3 \( \sigma \) limits on the N v doublet lines are \( N(\lambda 1238) \lesssim 6 \times 10^{12} \text{ cm}^{-2} \) and \( N(\lambda 1242) \lesssim 1 \times 10^{13} \text{ cm}^{-2} \). As for the low-ionization elements, the Mg II doublet is detected in correspondence with the high-redshift components of Si IV, and C II λ1334, Si II λλ1190, 1193, λ1526, λ1260, and Al II λ1670 absorptions are also present. \( N(\text{Fe II}) \lesssim 10^{12} \text{ cm}^{-2} \) is a 3 \( \sigma \) limit on the column density of Fe II λ2852.

The H I Ly\( \alpha \) line falls in the wavelength range of the UVES spectrum; the feature is heavily saturated. We obtained an acceptable fit with three components, even if the large values of the Doppler parameters and the velocity profiles of the metal absorptions suggest a more complex structure. We defer the analysis and discussion of this interesting system to a subsequent paper (D’Odorico & Petitjean 2000).

The Mg I λ2853 absorption tentatively detected by S98 has been identified with a telluric line by comparing the spectrum with that of a standard star obtained at comparable resolution.

5.1.19. System at \( z_{\text{abs}} = 1.92599 \)

Prominent Ly\( \alpha \) was observed at this redshift in the UCLES spectrum (O99). In the UVES spectrum, the C IV λλ1548, 1550 doublet is resolved. We fitted together C IV, Si IV λλ1334, 1402, and Si III λ1206 with three components, spanning ~60 km s\(^{-1}\). The N v λ1238 is blended with the C IV λ1550 of the system at \( z_{\text{abs}} = 1.337 \). The possible weaker component is visible, while the existence of the stronger one is ruled out by the absence of the corresponding N v λ1242 A line. As for the low-ionization lines, they show a shift of ~4 km s\(^{-1}\) with respect to the strongest component of the high-ionization absorptions. C II λ1334 has been fitted with two components, while for Si III λ1260 and a possible Mg II doublet, we fitted only the strongest one. The 3 \( \sigma \) limit on the abundance of Fe II based on the absorption at 2382 Å is \( N(\text{Fe II}) \lesssim 10^{11} \text{ cm}^{-2} \). A simultaneous fit of H I Ly\( \alpha \), Ly\( \beta \), Ly\( \alpha \), and Ly\( \gamma \) has been carried out.

5.1.20. System at \( z_{\text{abs}} = 1.9422 \)

This system presents many ions of different elements at different ionization stages. O99 and S98 already detected the absorption due to C II λ1334, Si II λλ1260, 1304, and Si III λ1206 and Si IV λλ1334, 1402, C IV λλ1548, 1550, Mg II λλ2796, 2803, Al III λλ1854, 1862, and C I λ1560, respectively.

The higher resolution and signal-to-noise ratio of the UVES spectrum make it possible to observe three new shallow components in C IV that are also present in H I Ly\( \alpha \). As for the strongest feature, C IV λλ1548, 1550 and Si III λ1206 are saturated and have been fitted following the velocity structure of Si IV λλ1334, 1402. The 3 \( \sigma \) limit on the N v column density is \( N(\text{N v}) \lesssim 4 \times 10^{12} \text{ cm}^{-2} \). The H I Ly\( \alpha \), Ly\( \gamma \), Ly\( \beta \), and Ly\( \alpha \) lines have been fitted with the same velocity structure as the C IV doublet, for a total column density of \( N(\text{H I}) \approx 2 \times 10^{16} \text{ cm}^{-2} \), in agreement with the measurement by Prochaska & Burles (1999).

The low-ionization lines C II λλ1334, Si II λλ1190, 1193, λ1260, λ1304, λ1526, Mg II λλ2803, Al II λ1670, and Al III λ1854 have been detected and fitted with the same velocity profile. Mg II λλ2796 was not considered in the fit, because its strongest component is affected by the presence of a telluric absorption line. We do not confirm the existence...
of the C τ 1560 absorption tentatively identified by S98. N(Fe II) ≤ 10^{14} cm^{-2} is the 3 σ limit on the abundance of Fe II based on the absorption at 2382 Å. A more complete discussion of these latter two interesting metal systems will appear in a further paper (D’Odorico & Petitjean 2000).

5.1.21. System at z_{abs} = 2.07728

This weak C IV doublet was identified by S98. We tentatively identified Si Ⅱ λ1206 and Fe Ⅱ λ2382 and a more reliable Si Ⅱ λ1260 absorption. The 3 σ limit on the Si Ⅱ λ1393 is N(Si Ⅱ) ≤ 9.8 × 10^{11} cm^{-2}, and that on C Ⅱ λ1334 is N(C Ⅱ) ≤ 4 × 10^{12} cm^{-2}. Unfortunately, the possible Mg Ⅱ λλ2796, 2803 absorptions at this redshift fall in the gap between the two UVES red-arm CCDs.

5.1.22. System at z_{abs} = 2.11287

This new, weak C IV doublet was fitted with two components. The corresponding H I Lyα line shows a column density N(H I) ≈ 8.1 × 10^{14} cm^{-2}.

5.2. Associated Systems

The associated systems observed in the redshift range 2.198–2.206 have been investigated by Petitjean & Srianand (1999). They found that most of the lines in these systems show the signature of partial coverage and the covering factor varies from species to species. In general, absolute abundances are close to solar, with the exception of the [N/C] abundance ratio, which is larger than solar. This result confirms the physical association of the absorbing gas with the active galactic nucleus.

5.2.1. System at z_{abs} = 2.19819

This associated system shows a strong C IV doublet at about −2000 km s^{-1} from the emission peak. O99 detected and fitted the N v doublet and the H I Lyα absorption line.

In the UVES spectrum we found a third, shallow component on the lower redshift side. C IV λλ1548, 1550, N v λλ1238, 1242, O vi λλ1031, 1037, H I Lyα, and H I Lyβ have been fitted together. The result of the fit is quite unsatisfactory (χ^2 = 9.5), because of the unusual ratio between the lines of the doublets. In particular, the O vi lines show a flat bottom—as if they were saturated—but a nonzero residual flux, a clear signature of partial coverage. The 3 σ limit on the Si iv λ1393 is N(Si iv) ≤ 1.1 × 10^{12} cm^{-2}.

5.2.2. System at z_{abs} = 2.20106

This new, broad and shallow system shows the lines N v λλ1238, 1242 and C IV λλ1548. C IV λ1550 and O vi λλ1031, 1037 are blended in the forest. The 3 σ limit on H I, from the absence of detectable H I Lyα, is N(H I) ≤ 1.3 × 10^{12} cm^{-2}.

5.2.3. System at z_{abs} = 2.2064

A multicomponent, broad C IV absorption in the redshift range between about −1400 and −1100 km s^{-1} from the emission peak was observed by S98. O99 fitted the N v λλ1238, 1242 and the H I Lyα with three components; the fit is complicated by uncertainty in the precise shape of the Lyα and N v emission-line continuum, and also, the N v λλ1242 from the z_{abs} = 2.198 system lies on top of the N v λλ1238.

We performed a simultaneous fit of the C IV, N v, O vi doublets and the H I Lyα with five components. The 3 σ limit on the Si iv column density is N(Si iv) ≤ 1.1 × 10^{12} cm^{-2}.

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