HST observations of the QSO pair Q1026–0045 A,B*

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Abstract. The spatial distribution of the Lyα forest is studied using new HST data for the quasar pair Q 1026–0045 A and B at \( z_{\text{em}} = 1.438 \) and 1.520 respectively. The angular separation is 36 arcsec and corresponds to transverse linear separations between lines of sight of \( \sim 300h_{50}^{-1} \) kpc \((q_0 = 0.5)\) over the redshift range \( 0.833 < z < 1.438 \). From the observed numbers of coincident and anti-coincident Lyα absorption lines, we conclude that, at this redshift, the Lyα structures have typical dimensions of \( \sim 500h_{50}^{-1} \) kpc, larger than the mean separation of the two lines of sight. The velocity difference, \( \Delta V \), between coincident lines is surprisingly small (4 and 8 pairs with \( \Delta V < 50 \) and 200 km s\(^{-1} \) respectively).

Metal line systems are present at \( z_{\text{abs}} = 1.2651 \) and 1.2969 in A, \( z_{\text{abs}} = 0.6320, 0.7090, 1.2651 \) and 1.4844 in B. In addition we tentatively identify a weak Mg \( ^{2+} \) system at \( z_{\text{abs}} = 0.11 \) in B. It is remarkable that the \( z_{\text{abs}} = 1.2651 \) system is common to both lines of sight. The system at \( z_{\text{abs}} = 1.4844 \) has strong O \( ^{1+} \) absorption.

There is a metal-poor associated system at \( z_{\text{abs}} = 1.4420 \) along the line of sight to A with complex velocity profile. We detect a strong Lyα absorption along the line of sight to B redshifted by only 300 km s\(^{-1} \) relatively to the associated system. It is tempting to interpret this as the presence of a disk of radius larger than \( 300h_{50}^{-1} \) kpc surrounding quasar A.

Key words: quasars: individual: Q 1026–0045 A, B, galaxies: ISM, quasars: absorption lines, galaxies: halo

1. Introduction

One way to probe the transverse extension of the gaseous structures giving rise to the Lyα forest seen in the spectrum of quasars is to observe multiple lines of sight to quasars with small angular separations on the sky and search the spectra for absorptions coincident in redshift.

This technique originated with a suggestion by Oort (1981) to test the possibility that the Lyα forest clouds originate in large pancake structures. The first discoveries of common and associated absorption using pairs of distinct quasars (with separations \( \sim 1 \) arcmin) were made by Shaver et al. (1982) and Shaver & Robertson (1983). These already indicated the possible existence of very large absorber sizes (hundreds of kpc), even for the Lyα clouds. At about the same time Sargent et al. (1982) found no detectable tendency for Lyα lines to correlate in QSO pairs separated by a few arcmin. Spectra of pairs of gravitational lens images revealed common absorptions on smaller scales (Weinman & Foltz 1983, Foltz et al. 1984). The idea that Lyα clouds might have large sizes remained controversial till the analysis by Smette et al. (1992), later confirmed by Dinshaw et al. (1994), Bechtold et al. (1994), Crotts et al. (1994a), Bechtold & Yee (1994), Smette et al. (1995), D’Odorico et al. (1998).

Recently, Dinshaw et al. (1995) derived a radius of \( 330h_{50}^{-1} \) kpc at \( z \sim 0.7 \) for spherical clouds from observation of Q0107–0232 and Q0107–0235 separated by 86 arcsec. Larger separations have been investigated by Crotts & Fang (1997) and Williger et al. (1997). Both studies conclude that the clouds should be correlated on scales larger than 500 kpc.

Here we present observations of Q1026–005 A \((m_r = 18.4, z_{\text{em}} = 1.438)\) and B \((m_r = 18.5, z_{\text{em}} = 1.520)\), two distinct quasars separated on the sky by 36 arcsec or 300 \( h_{50}^{-1} \) kpc \((q_0 = 0.5)\) at \( z \sim 1 \).

2. Observations

The observations were carried out on the Hubble Space Telescope using the Faint Object Spectrograph with the G270H grating over the wavelength range 2250–3250 Å, for a resolution of 1.92 Å FWHM. A total of 5300 s integration time was accumulated on both quasars. The data were calibrated using the
3. Results

3.1. The metal line systems

Metal line systems are present at \( z_{\text{abs}} = 1.2651 \) and 1.2699 in A, \( z_{\text{abs}} = 0.11, 0.6320, 0.7090, 1.2651 \) and 1.4844 in B.

In A, the system at \( z_{\text{abs}} = 1.2651 \) is detected by strong \( \text{H} \alpha \lambda 1025, \lambda 1215 \) absorptions and has a \( \text{Si IV} \lambda 1393, \lambda 1402 \) doublet associated. There are strong \( \text{H} \alpha \lambda 1025, \lambda 1215 \) absorptions at the same redshift along the line of sight to B. The fact that the positions of the \( \text{H} \alpha \) absorptions in A and B are nearly identical (\( \lambda 2753.67 \) and \( \lambda 2753.74 \) Å for \( \text{Ly} \alpha \)) respectively argues for the two absorptions being produced by the same object. If true the transverse dimension is larger than the 310 \( \text{kpc} \) separation between the two lines of sight. The system at \( z_{\text{abs}} = 1.2699 \) has strong \( \text{H} \alpha (w_{\lambda} (\text{Ly} \alpha) = 2.9 \text{ Å}), \text{C II}, \text{C III}, \text{O I}, \text{N III}, \text{Si II}, \text{Si III}, \text{Si IV} \) absorptions.

In B, both \( z_{\text{abs}} = 0.6320 \) and 0.7090 systems have strong \( \text{Si IV} \lambda 1526, \text{Fe II} \lambda 1608, \text{Al II} \lambda 1670 \) and \( \text{C IV} \lambda 1550 \) absorptions. As said before the \( z_{\text{abs}} = 1.2651 \) system is common to A and B. The presence of metals is revealed only by a \( \lambda 3155.87 \) feature that we identify as \( \text{Si IV} \lambda 1393 \). The associated \( \text{Si IV} \lambda 1402 \) line is not detected but could be lost in the noise. The strong system at \( z_{\text{abs}} = 1.4842 \) shows \( \text{N III}, \text{C III}, \text{C II}, \text{Si III} \) and possibly \( \text{O I} \) associated absorptions. \( \text{O I} \) absorption seems to be detected in most of the low and intermediate redshift systems (Bergeron et al. 1994, Vogel & Reimers 1995, Burles & Tytler 1996) and has been observed in a few high redshift Lyman systems (Kirkman & Tytler 1997). Although the velocity difference with the quasar is larger than 4000 km s\(^{-1}\), there is a possibility that the system is associated with the quasar. In addition we tentatively identify a weak \( (w_{\lambda} \sim 0.3 \text{ Å}) \text{ Mg II} \) system at \( z_{\text{abs}} = 0.11 \) in B. \( \text{Mg II} \lambda 2803 \) is possibly blended with \( \text{C IV} \lambda 1548 \) of a possible weak \( \text{C IV} \) system at \( z_{\text{abs}} = 1.0106 \).

3.2. The associated system in A and the proximity effect

There is a strong associated system detected in A by its \( \text{H} \alpha \) and \( \text{Ly} \beta \) absorptions. Two components are seen at \( z_{\text{abs}} = 1.4401 \) and 1.4420 with \( w_{\lambda} (\text{Ly} \alpha) = 0.58 \) and 0.40 Å respectively. The two components are redshifted relative to the QSO by 260 and 490 km s\(^{-1}\). Since the true redshift of the quasar is poorly known, these values are very uncertain. We do not detect any metal lines in the system. The \( \text{O VI} \) lines have \( w_{\lambda} < 0.20 \) Å; the \( \text{C IV} \) lines are redshifted outside the wavelength range of the data. Interestingly enough, there is a \( \text{H} \alpha \) absorption system

<table>
<thead>
<tr>
<th>( z_{\text{abs}} )</th>
<th>( w_{\lambda} ) (Å)</th>
<th>( \text{Ly} \alpha )</th>
<th>( \text{Ly} \beta )</th>
<th>( \text{H} \alpha )</th>
<th>( \text{C IV} )</th>
<th>( \text{Si IV} )</th>
</tr>
</thead>
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<td>0.53</td>
<td>1.28</td>
<td>1.277</td>
<td>0.45</td>
<td>0.60</td>
<td>0.60</td>
</tr>
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<td>1.441</td>
<td>1.28</td>
<td>0.60</td>
<td>0.60</td>
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<tr>
<td>1.2651</td>
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<td>1.373</td>
<td>1.28</td>
<td>0.60</td>
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<td>0.60</td>
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<tr>
<td>1.2699</td>
<td>0.30</td>
<td>1.28</td>
<td>1.277</td>
<td>0.45</td>
<td>0.60</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Table 1. Line list

(a) Coincidences are marked by a “C”, anti-coincidences by a “A” and ambiguous cases by a “u” for \( w_{\lambda} > 0.30 \) and 0.0 Å.

1 A column means uncertain value or identification
at \( z_{\text{abs}} = 1.4439 \) along the line of sight to Q 1026–0045B. The velocity difference between this system and the \( z_{\text{abs}} = 1.4420 \) in A is about 230 km s\(^{-1}\) only.

It is unlikely that the \( z_{\text{abs}} \sim z_{\text{em}} \) system is intrinsically associated with the central AGN. Such systems usually have high metal content and are expected to exhibit strong O \( \text{vi} \) and N \( \text{v} \) absorptions (Petitjean et al. 1994, Hamann 1997), absent from the spectra of Q1026–0045 A & B. The three absorptions are thus part of an object or group of objects which transversal dimension exceeds the 300h\(^{-1}\) kpc separation between the two lines of sight.

The absence of metals in the system associated with A, over the observed wavelength range, suggests an intergalactic origin. The higher velocity of the gas along the line of sight to B argues against the simple picture in which the gas would be collapsing toward A. In that case, we would expect the gas along the line of sight to B to have a projected velocity smaller than the velocity of the gas just in front of A. A model where the gas would be part of a rotating disk can be accommodated if the component at \( z = 1.4420 \) is at the same redshift as the quasar. In this case however one could wonder why the gas is metal deficient.

The relative equivalent widths of the hydrogen lines in the Lyman series of the system at \( z_{\text{abs}} = 1.4842 \) toward B are indicative of H i column densities in excess of \( 10^{16} \) cm\(^{-2}\). The presence of strong metal lines suggests that the gas is associated with the halo of a galaxy. Very deep imaging in this field to search for any enhanced density of objects would help to understand the nature of these intriguing systems.

There are only two systems in both lines of sight from \( z = 1.3436 \) to 1.520, the associated system in A (and its counterpart in B) and the metal system at \( z = 1.4842 \) in B. The number of lines with \( w_\gamma > 0.24 \) Å expected in this redshift range is 7±2 (Bahcall et al. 1996). It is probable that we see the effect of the enhanced photo-ionizing field due to the proximity of the quasars.

### 3.3. The Lyα forest

3.3.1. The line-lists

Table 1 lists all the absorption features detected at the 3\( \sigma \) level in the spectra. Identification of Lyα lines is sometimes uncertain due to blending with lines from the numerous metal line systems. We discuss here individual lines.

In Q 1026–0045A, the A2259 feature could be partly Ly\( \epsilon \) from the \( z_{\text{abs}} = 1.4420 \) system but given the strength of the other lines in the series, the contribution is most certainly negligible. There is a broad feature centered at 2452 Å that we decompose into two components at 2450 and 2454 Å. This feature is uncertain however. Galactic Fe \( \text{ii} \lambda 2374 \) absorption should not contribute too much to the A2375 feature that is mostly Ly\( \gamma \) at \( z_{\text{abs}} = 1.4405 \) and 1.4420. The line is quite strong however and could be partly produced by a Lyα absorption at \( z_{\text{abs}} = 0.9536 \). The two lines at A2458 and A2474 could correspond to a Si \( \text{iv} \lambda 1393,1402 \) doublet at \( z_{\text{abs}} = 0.7639 \). The corresponding C \( \text{ii} \lambda 1334 \) line would be blended with Ly\( \beta \) at \( z_{\text{abs}} = 1.2964 \) but the feature at \( \lambda 2736 \) could be C \( \text{iv} \lambda 1550 \) at the same redshift with no C \( \text{iv} \lambda 1548 \) detected. The line however is displaced by more than 1 Å from the expected position which is not acceptable. We thus consider the Si \( \text{iv} \) identification as doubtful.

In Q 1026–0045B, there is a broad feature at A2288.5 that cannot be accounted for by Si \( \text{iv} \lambda 1402 \) at \( z = 0.6320 \) only. The feature at \( \lambda 2376 \) may have a double structure. Ly\( \gamma \) at 1.4438 and Fe \( \text{ii} \lambda 2374 \) definitively contribute to this feature which is strong enough however to be partly produced by Lyα absorption at \( z_{\text{abs}} = 0.9545 \). Since C \( \text{iv} \lambda 1550 \) at \( z_{\text{abs}} = 0.6321 \) has \( \omega_{\text{obs}} = 0.46 \) Å, C \( \text{iv} \lambda 1548 \) at the same redshift should have \( \omega_{\text{obs}} < 0.92 \) Å. Consequently there is a Lyα line at \( z_{\text{abs}} = 1.0782 \) with \( \omega_{\text{obs}} > 0.6 \) Å.
We detect 11 and 12 Ly$\alpha$ lines with $w_\lambda > 0.2$ Å over the redshift range 0.8335–1.3436 along the lines of sight to A and B respectively. The density of lines with $w_\lambda > 0.24$ Å detected by the HST in the same redshift range is $\sim 17 \pm 3$ (Jannuzi et al. 1998). The number of lines we detect is thus small. This might be a consequence of blending effects. Two lines observed along A and B are said coincident when their redshifts are within 200 km s$^{-1}$ respectively. The Lyman forest is sparse at low redshift which implies that the probability for random coincidence is negligible (only 0.05 for $w_\lambda > 0.2$ Å). Last column of Table 1 indicates for each Ly$\alpha$ line with $w_\lambda > 0.2$, 0.3, 0.6 Å whether there is coincidence (C) or anti-coincidence (A). A letter (u) marks lines that are out of the sample or uncertain cases because of blending effects.

### 3.3.2. Correlations

The numbers of coincidences and anticoincidences for $w_\lambda > 0.2$, 0.3 and 0.6 Å are 4, 3, 1 and 7, 8, 3 respectively. Assuming that the Ly$\alpha$ clouds are spheres of radius $R$, we calculate the probability density for $R$ (see Fig. 2) following Fang et al. (1996). The peak of the probability is at $R = 267$, 305 and 364$h^{-1}$ kpc for $w_\lambda > 0.6$, 0.3 and 0.2 Å. There is a hint for the dimensions of the structures to be larger for smaller equivalent widths. This property is expected in simulations (Charlton et al. 1997). However as shown by Fang et al. (1996) and Crotts & Fang (1997), the radius determined by this method increases with the separation of the lines of sight indicating that the assumption of a single structure size is invalid. This has been recognized to be a characteristic of the spatial distribution of the Ly$\alpha$ gas in the simulations (Charlton et al. 1997). It is clear that better statistics in the data are needed to have a better understanding of the structures especially to discuss the difference between real size of the clouds and correlation length (Cen & Simcoe 1997).

It is intriguing to note that the velocity difference $\Delta V$ between lines coincident in redshift along the two lines of sight is small. Considering all the pairs, we find 4 and 8 pairs with $\Delta V < 50$ and 200 km s$^{-1}$ respectively. There is no pair, even along one single line of sight with $200 < \Delta V < 400$ km s$^{-1}$. This has been shown to favor disk-like structures (Charlton et al. 1995) but should be studied in more detail.

### Acknowledgements

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### References

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![Fig. 2. Probability distribution $P(R)$, normalized to one at its peak, and cumulative distribution versus cloud radius from the number of coincidences and anticoincidences of Ly$\alpha$ lines with $w_\lambda > 0.2$ (dashed-dotted lines), 0.3 (dashed lines) and 0.6 Å (solid lines). The peak of the probability is at $R = 267$, 305 and 364$h^{-1}$ kpc for $w_\lambda > 0.6$, 0.3 and 0.2 Å respectively.](image-url)