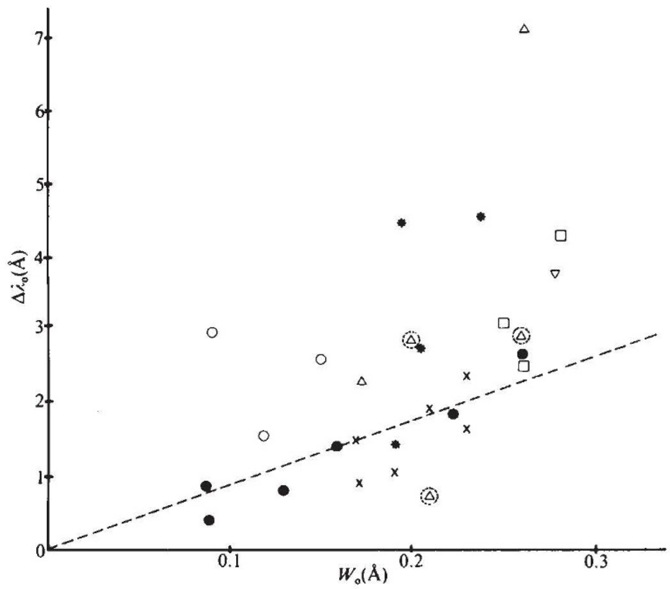

Fig. 2 A plot of distance at rest between the components of a doublet against the equivalent width at rest. ●, PKS0237−233; ×, B21225+31.7; △, PHL957; (△) correspond to those pairs of absorption lines in PHL957 whose doublet interpretation is impossible if the preliminary identification[5] of these lines as being produced by heavy elements were confirmed; ★, QSO0421+019; □, PKS2126−158; ▽, QSO0002+051; ○, QSO0119−046.

By using the mean radial distance between the Lyα absorption lines found in ref. 5 we can easily estimate the spatial density, n_s, of the progenitors for the shocks. Reducing this to the present, it appears that $n_s|_{z=0} \sim 10^{-75}$ cm^{-3}. Such coincidence by an order of magnitude with the spatial density of normal galaxies seems to agree with the hypothesis advanced earlier (see refs 2, 3) that the explosions in young galaxies (which took place presumably at the end of the 'bright phase', at $z \sim 10$) led to the formation of the intergalactic two-phase structure consisting of a large number of spherical cavities (hot rarefied regions) surrounded by rather thin, but dense and cold shells.

At the time corresponding to $z \approx 2$, these cavities should fill the main volume fraction, f, of the intergalactic medium, because $f = (4/3)\pi R_s^3 n_s|_{z=2} \sim 1$. By this time, most shocks have not intersected their neighbours. Therefore, a significant fraction of the absorption lines can be indeed observed in the form of doublets. In contrast, at smaller redshifts not only the doublet character of narrow absorption lines, but the very presence of numerous Lyα lines is hardly possible since the mutual intersections of shock waves are capable of disrupting any regular structure formed previously [It is tempting to speculate that this may explain decrease of the Lyα line density at $z < 2$ noted in ref. 16.]

To conclude, we stress the necessity of further searches for the absorption Lyα doublets among the most narrow absorption lines with $\lambda < \lambda^{\mathrm{emiss}}_{\mathrm{Ly}\alpha}$ in the spectra of very distant quasars ($z \gtrsim 2$). If observations with the same, or still higher, resolution confirm the hypothesis advanced above that such doublets are conditioned by absorptions in intergalactic shock waves there would appear to be an opportunity of directly investigating the physical properties of intergalactic gas and its evolutional history.

A referee has pointed out that an analysis of the Lyα lines produced in metagalactic shocks (without any direct observational evidence for the model such as presented above) has been carried out in an unpublished paper by S. Ikeuchi, K. Tomisaka and J. P. Ostriker.

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A new test of the cosmological interpretation of QSO redshifts

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Close QSO pairs can be used to test the cosmological interpretation of QSO redshifts. If (some of) the narrow absorption lines in QSO spectra arise in intervening matter, and if QSOs are surrounded by gaseous haloes or located in regions of high matter density (for example, clusters of galaxies), one may expect to find absorption in the spectrum of one QSO at the redshift of a foreground QSO which happens to be located nearby on the plane of the sky ('associated absorption'). According to the cosmological interpretation, the foreground QSO should have the lower redshift. If, on the other hand, QSO redshifts are unrelated to their distances, one would expect to find as many cases in which the foreground QSO has the higher redshift of the two; or if the absorption lines are not even due to intervening matter, there should be no coincidences of absorption and emission redshifts beyond random expectation. Thus, by using associated absorption to distinguish which QSO of a pair is in front of the other, we have a simple and straightforward test of the cosmological interpretation.

The symmetry of QSO pairs—the fact that both members are QSOs—renders them particularly powerful tools for testing the cosmological interpretation of QSO redshifts. QSO–galaxy pairs, for example, do not share this symmetry, and can only be used to demonstrate that QSOs are at least as distant as the galaxies (in principle, the QSOs could be embedded in the haloes of the galaxies).

The QSO pairs which are presently available are listed in Table 1. In all cases the relevant absorption lines with equivalent widths of at least 1 Å could be detected over the appropriate redshift range. Cases where confusion is likely (for example, in the Lyα 'forest') have been excluded. Table 1 is inhomogeneous insofar as different lines (Mg II, C IV and Lyα) have been used in different cases, but we note that the equivalent width of Lyα is greater than that of C IV 1,548 by a factor of three on average, so an absence of Lyα absorption probably also implies an absence of C IV absorption.

Four cases have been found in which associated absorption is present at z_{em} (lower) (within $|z_{\mathrm{abs}} - z_{\mathrm{em}}|/(1+z_{\mathrm{em}}) = 0.0067$, which corresponds to 2,000 km s^{-1} if the redshifts are Doppler, this being about the maximum for which correlations between galaxies might be expected; see refs 1, 2). Considering the average number density of heavy-element absorption systems[2], the probability of these coincidences occurring by chance with a random distribution of redshifts is $<10^{-3}$. Furthermore, they occur mostly among the QSO pairs having the smallest angular

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Table 1 Associated absorption in close pairs of QSOs

QSO pair	Separation (arc min)	Associated absorption at z_{em} (lower): z_{em}	Relevant lines	$\frac{\lvert z_{abs}-z_{em}\rvert}{(1+z_{em})}$	Associated absorption at z_{em} (higher): z_{em}	Relevant lines	$\frac{\lvert z_{abs}-z_{em}\rvert}{(1+z_{em})}$
1548+114A, B*	0.1	0.44	MgII	0.0047	1.90	–	–
2359–022A, B†	1.0	0.86	–	–	2.81	Lyα	>
0307–195A, B‡	1.0	2.12	C IV, Lyα	0.0003	2.14	C IV, Lyα	>
0254–334A, B§	1.0	1.86	C IV	>	1.91	C IV	>
0028,9+003‖	1.0	1.73	C IV	0.0006	2.22	C IV	>
2206–199A, B†	2.1	1.58	–	–	2.55	Lyα	>
1623+268,9¶	2.9	2.52	–	–	2.61	Lyα	>
1228+076,7#	3.4	1.88	C IV	0.0067	2.39	–	–
1604+176,7†	4.4	2.04	C IV	>	2.32	–	–
2224–408A, B†	4.8	1.95	C IV	>	2.33	Lyα	>
0203–497,8†	5.7	1.44	C IV	>	2.60	Lyβ	>

> Indicates $|z_{abs}-z_{em}|/(1+z_{em})>0.0067$; – indicates that the data are either inadequate or ambiguous, and these cases were not included in the statistical calculations.

* Ref. 3; † this study; ‡ ref. 4; § ref. 5; ‖ ref. 6; ¶ ref. 7; # ref. 8.

separations. This provides strong evidence that these absorption lines are due to intervening matter, and that at least some QSOs are surrounded by diffuse matter (for example, extended haloes or clusters of galaxies).

On the other hand, no cases have been found of associated absorption at z_{em} (higher). There seems to be a clear asymmetry: associated absorption is sometimes found at z_{em} (lower) but never at z_{em} (higher). Application of the Fisher exact probability test (which uses the presence or absence of associated absorption on a simple yes–no basis) to Table 1 shows that the probability that QSO redshifts are randomly distributed with distance is only 0.04. It appears that the foreground QSO always has the lower redshift.

Indeed, the mere existence of the phenomenon of associated absorption presents severe obstacles (of an astrophysical nature) to non-cosmological interpretations of redshifts. The fact that several cases are now known firmly establishes that these are not chance coincidences—the absorption is really associated with the foreground QSO. A non-cosmological (emission) redshift of that QSO would therefore require an identical non-cosmological origin for the associated absorption redshift, yet the absorption presumably arises in a region of quite different physical conditions. Furthermore, if many absorption systems are intervening (the present evidence based on associated absorption may soon be augmented by searches for common absorption at the same redshift in both spectra of very close pairs of QSOs), the absence of absorption systems with far higher redshifts than the emission redshifts of individual QSOs will provide a very strong argument against noncosmological interpretations.

While the present results are not totally conclusive, it should be noted that the sample of QSO pairs can easily be expanded, making possible far stronger conclusions (extending also the sub-samples of QSOs) and other variations of these tests. These results, of course, say nothing about the actual relationship between redshift and distance, but they do indicate that higher-redshift QSOs are more distant than lower-redshift QSOs, and, if substantiated by further observations, this will be sufficient to eliminate the hypothesis that QSO redshifts are unrelated to distance.

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Discovery of DHM0054–284, a quasar of redshift 3.61

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We report here the discovery of a quasar of redshift 3.61 detected in a broad band survey of stars using COSMOS measurements of UK Schmidt Telescope (UKST) photographs. The identification of the object as a quasar was confirmed by spectroscopic observations made with the Anglo-Australian Telescope (AAT). The quasar's redshift is the second highest so far detected and the highest for a quasar discovered using purely optical techniques. We describe here the search for DHM0054–284 and then suggest that the methods provide an efficient way of finding more high-redshift quasars.

The procedure began with the measurement by the COSMOS machine[1] of U, B, V and R UKST photographs to obtain magnitudes and positions for 20,000 stars with $B<21$ mag in a $4°\times4°$ area of sky. The area of sky surveyed was centred on the south galactic pole and the COSMOS magnitudes were calibrated using standard star sequences in the field[2,3]. An objective prism photograph of this area of sky had previously been surveyed by eye in a search for emission line quasars[4]. This revealed the positions of 73 candidate quasars in our measured region. Many of these quasars have redshifts estimated from the objective prism spectra. By identifying these images we were able to find their colours in our magnitude system and these proved to be of great help in indicating the likely colours of higher redshift quasars.

Figure 1 plots $U-B, B-V$ and $V-R$ colour against redshift for every quasar identified in the prism survey that had an estimated redshift and that was identified by COSMOS as a star (44 images). The colours are zero pointed in the Johnson system (although the B photographic passband, in particular, is wider than the standard Johnson passband). The estimated r.m.s. error on the colours are ±0.25 mag. Full details of the photometry techniques used will be given elsewhere. Although not all of the objective prism quasars are confirmed as such, where slit spectra have been obtained the proportion of quasars has been found to be $>90\%$. In these cases, the slit spectra show that the objective prism estimates of the redshifts are accurate to ±0.1.

