ABSTRACT

We report the detection of a large void (~7 Mpc) between the redshifts 2.16286 and 2.20748 in the Lyα forest of Tol 1038 – 2712. This void is centered near a foreground QSO Tol 1037 – 2704, which is at a distance ~4.4 Mpc away from the void. We estimate the probability for the void to occur by chance in front of the foreground QSO to be a few times 10^-3. We discuss the implications of the void being produced by excess ionization due to the foreground QSO.

Subject headings: galaxies: clusters: general — intergalactic medium — quasars: absorption lines — quasars: individual (Tol 1038 – 2712)

RADIATION-INDUCED VOID IN THE SPECTRUM OF TOL 1038 – 2712

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1. INTRODUCTION

Lyα lines seen in the spectra of QSOs are believed to be produced by neutral hydrogen clouds in the intergalactic medium (IGM). Being the most abundant objects at higher redshifts, Lyα clouds can provide valuable information regarding the IGM over a wide span of look-back time. Bajtlik, Duncan, & Ostriker (1988, hereafter BDO) have shown that the deficit of lines seen in the Lyα forest close to the QSOs, known as the proximity effect, can be used to estimate the intensity of the ionizing UV background radiation. We also provide the redshift distribution, which is calculated based on the high-resolution sample compiled by Srianand & Khare (1994, hereafter SK94), in Table 1. Other information given in the table are the total number of lines used in the analysis, the total redshift path, and the average separation between the two QSOs. We perform numerical simulations to estimate the chance probability for the occurrence of a gap near the foreground QSO.

We have developed a Monte Carlo code to generate artificial line lists. In our numerical simulations, we assume no evolution in the number density of Lyα clouds with redshift since this is true for small-redshift intervals. The distribution of the number of Lyα clouds along the line of sight is assumed to be Poissonian with the mean given in Table 1. We generate 50,000 line lists for the QSO Tol 1038 – 2712 by considering the observed redshift window. We repeat the simulations for two different values of the number of Lyα clouds per unit redshift (as given in Table 1). Using these simulated line lists, we estimate the probability for obtaining a spectrum with at least one gap greater than Δz, with the total number of lines the same as the observed one. The probability is the ratio of the number of simulated line lists satisfying the above noted conditions to the total number of simulations. The resulting probability distribution, P(>Δz), for different values of Δz is given in Figure 2. We also estimate P(>Δz) by constraining the gap so as to occur close to the foreground quasar. The probability of an occurrence of a gap with a size greater than the observed void anywhere in the spectrum and close to the foreground QSO is given in Table 2 (P1 and P2, respectively). The probability of finding a gap by chance that is similar to, or greater than, the observed void is a few times 10^-3. Thus, the presence of the void is real and is not due to any random fluctuations in the interline spacing of Lyα clouds. In what follows, we discuss various implications of the presence of this void.

2. VOID IN THE LYα FOREST

The distribution of Lyα clouds and QSOs in the field of the Tololo group of QSOs are shown in Figure 1 (coordinates of the QSOs are taken from Jakobsen & Perryman 1992). One can clearly see an apparent lack of Lyα absorption lines along the line of sight to Tol 1038 – 2712 (between redshifts 2.1652 and 2.2075) close to the foreground QSO Tol 1037 – 2704 (z_em = 2.195). The angular separation between the two QSOs is 17.9. This corresponds to a proper separation of 4.4 h^-1 Mpc at z = 2.195. The redshift difference 0.0422 at z = 2.195 gives a proper length of ~7 h^-1 Mpc for the void.

We estimate the number of Lyα clouds per unit redshift, N(z), for the Lyα lines along four QSO sight lines (taken from Dinshaw & Impey 1996) using the maximum likelihood method. We consider only the lines that are 3 Mpc away from the QSOs. The result obtained using the lines with rest equivalent width greater than 0.1 Å is given in Table 1. We also provide the redshift distribution, which is calculated based on the high-resolution sample compiled by Srianand & Khare (1994, hereafter SK94), in Table 1. Other information given in the table are the total number of lines used in the analysis, the total redshift path, and the average separation between the two QSOs. We perform numerical simulations to estimate the chance probability for the occurrence of a gap near the foreground QSO.

3. IMPLICATIONS OF THE VOID

3.1. Background Radiation Field

The presence of a foreground QSO close the center of the void naturally favors the void being produced by the prox-
iminity effect. If this is true, one can get a bound on the intensity of ionizing UV background radiation, $J_{\nu}$. We assume that the QSO radiation is emitted isotropically and has not varied much over a long timescale. We calculate the continuum flux at the Lyman limit for each QSO in the field from its $B$ magnitude (Jakobson & Perrymann 1992), assuming that the spectral energy distribution of the QSOs is a power law, $f_\nu \propto \nu^{-\alpha}$ (with spectral index $\alpha = 0.636 \pm 0.303$ estimated from Tytler & Fan 1992). We do not introduce any correction to the magnitude that is due to emission-line flux since the estimated emission-line contribution to the observed magnitude of quasars in the redshift window $2-2.5$ is very low (between 0.005 and 0.025).

In Figure 3, we have plotted the total Lyman limit flux seen by each Ly$\alpha$ cloud, which is due to all the known QSOs in the field, against the absorption redshift. We use the redshifts of the quasars given in Jakobson & Perrymann (1992). These redshifts are based mainly on high-ionization lines and may be underestimates of the actual redshifts. This will introduce a small error in the calculations of the flux (Srianand & Khare 1996). We have not tried to correct the emission redshifts in our analysis since the redshifts due to low-ionization emission lines are not available. In the calculations, we have not taken into account the absorption along the line of sight since the redshift path lengths are small. The quoted error bars are errors in flux due to 1 $\sigma$.
Fig. 2.—Probability for the occurrence of at least one interline spacing greater than $\Delta z$ within the redshift coverage similar to $1038-2712$, calculated using the numerical simulations.

uncertainty in the mean spectral index. The background radiation values quoted by various authors in the literature are also plotted in Figure 3.

The calculated Lyman limit flux at the center of the void is $\log (f/4\pi) = -21.47^{+0.04}_{-0.03}$ ergs s$^{-1}$ cm$^{-2}$ Hz$^{-1}$ sr$^{-1}$. Thus, the implied upper limit of the background radiation field at $z \sim 2.19$ is

$$\log (J_e) \leq -21.47^{+0.04}_{-0.03} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1}.$$  \hspace{1cm} (1)

in ergs s$^{-1}$ cm$^{-2}$ Hz$^{-1}$ sr$^{-1}$. This value is consistent with the lower limit, $-21.80$ ergs s$^{-1}$ cm$^{-2}$ Hz$^{-1}$ sr$^{-1}$, quoted by Fernandez-Soto et al. (1995), based on the proximity effect on the Ly$\alpha$ forest due to foreground QSOs. It is clear from Figure 3 that the quoted upper limit is lower than most of the values available in the literature that are based on the proximity effect.

We perform the standard proximity effect calculations prescribed by BDO using the available Ly$\alpha$ data along the four QSO sight lines in the field. We calculate the expected number of lines in different relative velocity bins with respect to QSOs for the column density distribution index, $\beta = 1.5$, and the rest equivalent width cutoff $0.1$ Å. In these calculations, we assume no evolution for the number density of Ly$\alpha$ clouds and use the mean number densities given in Table 1. The ratio of the expected number, $N_{\text{exp}}$, to the observed number, $N_{\text{obs}}$, of Ly$\alpha$ clouds in different relative velocity bins with respect to the QSOs are given in Figure 4 for three different values of the background intensity. The error bars are calculated by considering the distribution of the number of lines along the line of sight to be Poissonian.

When we consider the background intensity value to be equal to the obtained upper limit, the I model underpredicts the number of Ly$\alpha$ clouds near the QSO by more than 2 $\sigma$ level (top panel in Fig. 3). The predicted distribution, however, is consistent with the background value estimated by BDO and Bechtold (1994) (bottom panel in Fig. 3). The disagreement between the values of the background intensity, calculated using the two different methods, can be accounted for if either our assumption of isotropic emission is wrong or the QSO luminosity has varied within the light-travel time between the QSO and the void. In the following sections, we discuss the implications of these possibilities in detail. As noted by the referee, both $1037-2704$ and $1038-2712$ display broad absorption line (BAL) characteristics, although the classification is still uncertain (Dinshaw et al. 1995).
& Impey 1996; Lespine & Petitjean 1996). If the QSOs are indeed BAL QSOs, then the radiation seen by the Ly\alpha line of sight will be less than the values used in our proximity effect calculations. This will reduce the difference in the background intensities estimated using the two different methods discussed above.

3.2. Long-Term Fading of QSOs

In this section, we assume the emission from the QSO to be isotropic and try to get constraints on different QSO evolution models based on the background radiation values estimated from the foreground void and line-of-sight proximity effect calculations. One can estimate the lower limit on the lifetime of the QSO from its distance from the void (Dobrzycki & Bechtold 1991). The separation of 4.4 Mpc corresponds to a light-travel time of \(1.4 \times 10^7\) yr. Thus, the lifetime of the foreground QSO Tol. 1037 — 270 is

\[
t_{\text{qso}} \geq 1.4 \times 10^7\ \text{yr}.
\]

The observed luminosity evolution of QSOs can be interpreted as (a) the evolution of a single long-lived (\(t_{\text{qso}} = 10^{10}\) yr) population of QSOs or (b) the evolution of successive generations of short-lived QSOs (\(t_{\text{qso}} = 10^8\) yr). Our estimated lower limit is consistent with both of the models for QSOs. Boyle, Jones, & Shanks (1991) have shown that the luminosity evolution of QSOs can be parameterized by

\[
L(z) \propto (1 + z)^k,
\]

with the best-fitted value of \(k = 3.45 \pm 0.10\). Thus, in the case of a long-lived population, the luminosity of QSOs will not change within the light-travel time between Tol 1037 — 270 and the void. Both models are consistent if the background intensity is less than the upper limit quoted in the previous section, based on the presence of the void. However, if the actual background value is higher than the upper limit quoted here, as suggested by the general proximity effect estimates, one will need a reduction in the luminosity of Tol 1037 — 270 by a factor greater than 2 — 16 within \(1.4 \times 10^7\) yr. Dobrzycki & Bechtold (1991) identified a void in the spectra of Q0302—003 that was close to the foreground QSO Q0301 — 005. Unlike the present case, the void is displaced from the foreground QSO toward the lower wavelength side. The distance between the center of the void and Q0301 — 005 is 4.25 Mpc. The corresponding light-travel time is \(1.34 \times 10^7\) yr. The estimated Lyman limit flux from the QSO at the center of the void is \(10^{-21.8}\) ergs s\(^{-1}\) cm\(^{-2}\) Hz\(^{-1}\) sr\(^{-1}\). Thus, for the different background value estimated in the literature, Q0301 — 005 (like Tol 1037 — 270) also needs a reduction in the luminosity by a factor greater than 3 — 40 within \(1.4 \times 10^7\) yr. Fading of QSOs within such a short timescale cannot be explained by the long-lived QSO models. Thus, if the intensity of the background radiation is high, and if the QSOs radiate isotropically, the observation of voids that are due to the foreground QSOs favors models in which the luminosity evolution is realized as the superposition of activities in successive generations of short-lived QSOs (Hachnelt & Rees 1993).

It is known that the long-lived interpretation has problems with observations. It predicts larger remnant black holes (\(\sim 10^9 M_\odot\)) and smaller Eddington ratios (\(\sim 0.001\)) in low-redshift active galactic nuclei than are currently inferred from emission-line and continuum studies (Padovani 1989). Our analysis gives independent observational proof against the long-lived QSO interpretation.

3.3. Anisotropic Emission in QSOs

Crotts (1989) has suggested that anisotropic emission from QSOs might explain the absence of the proximity effect that is due to foreground QSOs. If Tol 1037 — 2704 is not an isotropic emitter and has not varied, then we require an excess collimated beam (with radiation roughly an order of magnitude more compared with that along our line of sight) within a cone of angle 76° perpendicular to the line of sight.

Dobrzycki & Bechtold (1991), in order to explain the displaced void, proposed an opening angle of 140°, assuming the radiation toward the void is the same as that received along our line of sight. If their assumption is true, one should see a void in the spectrum of Q0301 — 005 close to the emission redshift along our line of sight. We do not find any such deficit in the intermediate-resolution spectra of Q0301 — 005 observed by Steidel (1990), and the simple assumption of Dobrzycki & Bechtold (1991) may not be correct. The distribution of lines near this QSO is consistent with high values of background radiation. The void can be explained if the excess collimated beam is within a cone angle less than 70°. Thus, the foreground void in both cases favors a narrow collimated beam in excess of an isotropic emission rather than a wide-angled cone of emission caused by shadowing of a portion of the emission. However, more observations are needed to get a clear picture about the beaming models.

4. CONCLUSIONS

We have reported here the detection of a void (\(~ 7\) Mpc) in the spectrum of QSO Tol 1038 — 2712 close to the foreground QSO Tol 1037 — 2704. Using numerical simulations, we have shown that the chance probability of the occurrence of the void close to the foreground QSO is \(~ 10^{-3}\).

We have estimated the upper limit on the intensity of the background radiation field to be \(-21.47^{+0.04}_{-0.03}\) ergs s\(^{-1}\) cm\(^{-2}\) Hz\(^{-1}\) sr\(^{-1}\) assuming the void is produced by the proximity effect of the foreground QSO. Based on the I model and Ly\alpha lines along four QSO sight lines, we have shown that the actual background intensity is higher than the estimated upper limit. We discuss two possibilities in order to account for this difference.

If QSOs emit isotropically, the presence of the void will be more observational proof against long-lived population models of QSOs. If the QSO does not vary within a few times \(10^7\) yr, our result suggests a narrow collimated cone emission toward the void (with flux an order of magnitude higher) in addition to the isotropic emission being a possible source of the void.

Most of the available observations of pairs of QSO spectra to date (Crotts 1989; Fernández-Soto et al. 1996) fail to detect voids near foreground QSOs. Even in the two cases where voids have been detected, one is found at the redshift of the foreground QSO, and the other is at redshift less than that of the foreground QSO. If the beaming picture is correct, one would like to see a void displaced toward the higher wavelength side also. Thus, a case with a void displaced toward the higher wavelength side will confirm the beaming arguments.
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