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LBQS 0103−2753: A 0″.3 BINARY QUASAR[1]

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ABSTRACT

Imaging and spectroscopy with the *Hubble Space Telescope* show that LBQS 0103−2753 ($V = 17.8$, $z = 0.848$) is a binary quasar with a separation of 0″.3, or 2.3 kpc. This is by far the smallest separation binary quasar reported to date. The two components have very different spectra, including the presence of strong broad absorption lines (BALs) in component A only. The emission-line redshifts, based on the broad high-ionization C IV lines, are $z_A = 0.834$ and $z_B = 0.858$; their difference is 3900 km s^{-1} in velocity units. The broad C IV lines, however, are probably not a good indicator of systemic redshift; and LBQS 0103−2753A and B could have a much smaller systemic redshift difference, like the other known binary quasars. If the systemic redshift difference is small, then LBQS 0103−2753 would most likely be a galaxy merger that has led to a binary supermassive black hole. There is now one known 0″.3 binary among roughly 500 QSOs that have been observed in a way that would reveal such a close binary. This suggests that QSO activity is substantially more likely for black hole binaries at spacings ∼2 kpc than at ∼15 to 60 kpc. Between 1987 and 1998, the observed Mg II BAL disappeared.

Subject headings: black hole physics — galaxies: active — quasars: general — quasars: individual (LBQS 0103−2753)

1. INTRODUCTION

Quasar pairs are known to represent three classes of objects: chance alignments, gravitational lenses, and binary quasars. Binary quasars are rare; in the Large Bright Quasar Survey (LBQS) sample of $\sim 10^3$ quasars, Hewett et al. (1998) find two binaries. A similar rate of occurrence is found for all quasars in the literature: 11 QSO pairs in $\sim 10^4$ quasars (Kochanek, Falco, & Muñoz 1999). This rate is high compared with the naive extrapolation of the quasar-to-quasar two-point correlation function at megaparsec separations to separations of less than 100 kpc (Djorgovski 1991). The existence of binary quasars, as distinct from the gravitationally lensed pairs, has been established by the occurrence of quasar pairs with only one radio-loud member (e.g., Djorgovski et al. 1987) and by the statistics of QSO pairs with large (≳3″.0) separations (Kochanek et al. 1999). Kochanek et al. find that quasar pairs with $\Delta\theta \leq 3''.0$ are gravitational lenses and that most quasar pairs with $\Delta\theta > 3''.0$ are binary quasars. The leading explanation for binary quasars is the fueling of quasar activity when two galaxies with massive black holes in their nuclei collide (Kochanek et al. 1999).

The observation that two nearby quasar images have similar emission-line spectra is insufficient to allow classification as a lens (e.g., Mortlock, Webster, & Francis 1999), and gravitational lens pairs can have different emission-line spectra because of reddening or time delays. However, quasar pairs with almost identical redshifts but very different emission-line spectra or broad absorption lines (BALs) are probably binary quasars. The cloverleaf QSO, H1413+114, with $\Delta\theta_{max} = 1''.4$, is a four-image gravitational lens; all four images show BALs (e.g., Monier, Turnshek, & Lupie 1998). HS 1216+5032, with $\Delta\theta = 9''$, is a binary QSO with one BALQSO and one non-BALQSO (Hagen et al. 1996).

Here we report the serendipitous discovery that LBQS 0103−2753 is a binary quasar with a projected separation of 0″.30 on the sky. The two components show large differences in their emission-line spectra, and only one has BALs. LBQS 0103−2753 is one of eight BALQSOs observed in a program of *HST*/Space Telescope Imaging Spectrograph (STIS) and ground-based spectrophotometry of low- and medium-redshift BALQSOs for studies of chemical abundances. The selection criteria were the presence of BALs (both high- and low-ionization BALQSOs were candidates), a redshift in the range of $0.4 < z < 1.8$, and high apparent brightness. LBQS 0103−2753, $z_e = 0.848$, was chosen based on its apparent magnitude, $B_J = 18.1$, and its LBQS spectrum showing broad, deep Mg II λ2798 absorption around $z_a = 0.769$ (Morris et al. 1991).

2. OBSERVATIONS

Observations of LBQS 0103−2753 were obtained on 1999 July 17–18 (UT). Figure 1 shows the STIS CCD acquisition image, which involved a 10 s integration time in the F28X50LP mode (a transmission from about 5000 to 10,000 Å, $\lambda_{pivot} = 7228.5$ Å) with a standard 100 × 100 subimage readout. The image has total counts of 1113 and 356 DN for A and B (with formal errors of 1.8% and 4.1%), respectively, using a 3 pixel radius photometry aperture and a much larger annulus for sky. The A/B flux ratio is 3.1, probably a slight underestimate due to the wings of image A leaking into image B. The centroids are separated by $\Delta\theta = 0''.295 \pm 0''.011$. The FWHMs of the images are 2.1 and 2.3 pixels for A and B, respectively, consistent with point sources. The position angle (P.A.) of the image $+y$-axis is P.A. = −149.7, and the P.A. connecting A and B is −149°.9 or 30°.1 ± 2°.2, with A north and east of B.

The QSO pair is almost perfectly aligned with the STIS slit, which is itself aligned along the image $+y$-axis. A three-step peak-up into the 52 × 0.2 (0″.2-wide) aperture was used for the spectroscopic observations with the STIS NUV-MAMA using

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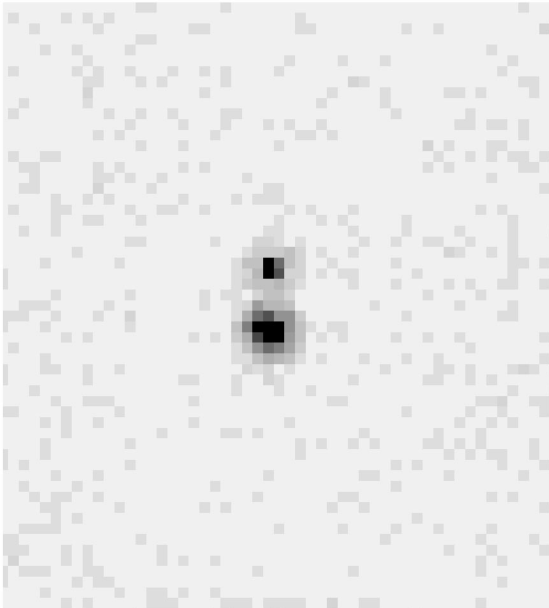

FIG. 1.—Acquisition image of LBQS 0103−2753 obtained with the STIS CCD in the 28X50LP mode. The brighter object is A, the BALQSO, and the fainter is B. The P.A. of the $+y$-axis in this picture is at $-149\overset{\circ}{.}7$ measured east from north.

the G230L grating. Four orbits gave a total integration time of 10,907 s. The spectra of the two QSOs are shown in Figure 2. The spectra were extracted from the NUV-MAMA image using the standard STSDAS/CALSTIS routine "x1d" with an 11 pixel–wide extraction box for each QSO. The measured separation of the two spectra near the center of the NUV-MAMA image is 11.9 pixels or $0\overset{''}{.}295$, in agreement with the acquisition image. Inspection of plots perpendicular to the dispersion shows that the two spectra have very little (<5%) contamination from each other. The nominal resolution at 2400 Å is 2.1 pixels FWHM, or 3.3 Å, for the 1.55 Å pixel^{-1} sampling. The useful wavelength range of the two spectra is from 1650 Å (where the signal-to-noise ratio [S/N] is ~1) to 3145 Å. The S/N in the continuum around 2600 Å is about 20 pixel^{-1} for component A and 11 pixel^{-1} for component B.

An optical spectrum of LBQS 0103−2753 (sum of both components) was obtained on 1998 August 22 (UT) using the CTIO Blanco 4 m telescope. The Ritchey-Chrétien spectrograph with the Blue Air Schmidt and Loral 3K CCD with a 632 line mm^{-1} grating was used to obtain a 3.0 Å FWHM resolution spectrum covering 3050–5975 Å. The spectrum is shown in Figure 3 along with the LBQS spectrum obtained on 1987 August 26 (UT) by Morris et al. (1991).

3. ANALYSIS

At $z = 0.848$, the projected separation of $0\overset{''}{.}30$ amounts to 2.3 kpc ($H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$). For comparison, the next smallest reliable binary quasar known, J1643−3156, has an apparent separation of 15 kpc (Brotherton et al. 1999). Table 1 compares LBQS 0103−2753 with the next smallest binary quasars and other BAL/non-BAL quasar pairs (also see lists by Mortlock et al. 1999 and Kochanek et al. 1999).

The STIS spectra of LBQS 0103−2753A and B show that the two components of this QSO pair have very different emis-

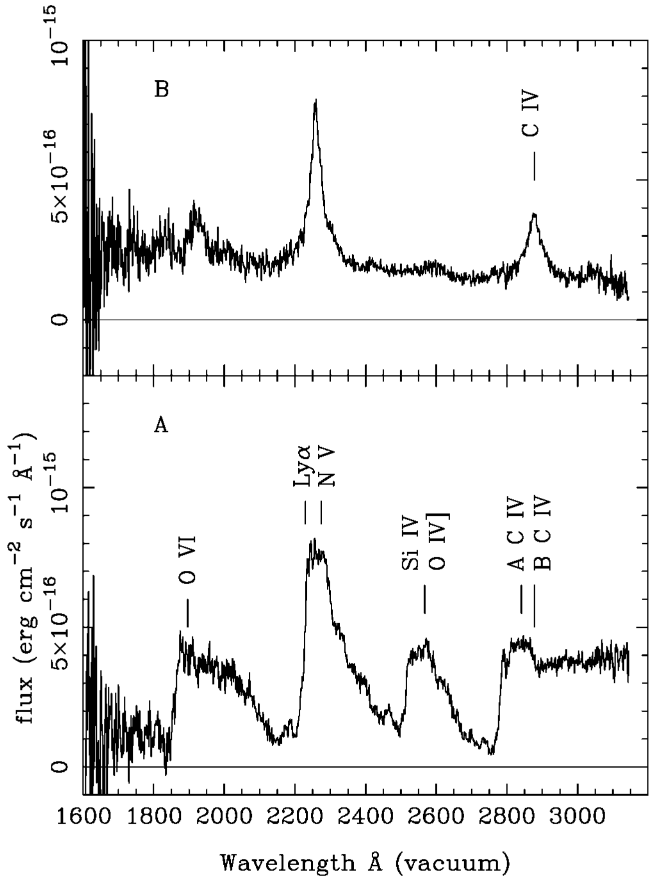

FIG. 2.—Spectra of LBQS 0103−2753A and B obtained with *HST*/STIS using the NUV-MAMA and G230L grating. The upper panel is component B, and the lower panel is component A. The measured C IV λ1549 emission-line wavelengths for components A and B are both shown with vertical marks above component A's C IV λ1549 emission line.

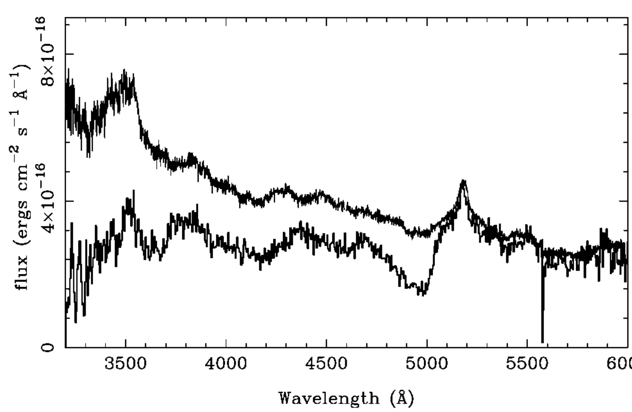

FIG. 3.—Spectra of LBQS 0103−2753A plus B (the sum of the images). The upper spectrum is from CTIO obtained on 1998 August 22 (UT), and the lower spectrum, at somewhat lower resolution and S/N, is from the LBQS obtained on 1987 August 26 (UT; Morris et al. 1991). The strong absorption around 4950 Å in the LBQS spectrum is an Mg II λ2798 BAL. The LBQS spectrum has been scaled to make the spectra match at the red end.

TABLE 1
BINARY QUASARS AND BINARY QUASAR CANDIDATES

Name	z_e	$\Delta\theta$ (arcsec)	R[a] (kpc)	m (brighter)	Δm	Comment	References
Close Pairs							
LBQS 0103−2753	0.848	0.3	2.3	18.2	1.2:	BAL/non-BAL pair	1
J1643+3156	0.586	2.3	15	18.4	0.8	Radio-loud/radio-quiet pair	2
CTQ 839	2.24	2.1	17	18.2	1.9	Radio-quiet/radio-quiet pair	3
Other BAL/Non-BAL Pairs							
LBQS 2153−2056	1.85	7.8	66	17.9	3.4	BAL/non-BAL pair	4
HS 1216+5032	1.45	9.1	77	17.2	1.8	BAL/non-BAL pair	5, 6
Q1343+2640[b]	2.03	9.5	79	20.2	0.1	Weak BAL/non-BAL pair	7

[a] The projected separation R is calculated using $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.
[b] Q1343+2640 is also a radio-loud/radio-quiet pair (Kochanek et al. 1999).
REFERENCES.—(1) This Letter; (2) Brotherton et al. 1999; (3) Morgan et al. 2000; (4) Hewett et al. 1998; (5) Hagen et al. 1996; (6) Lopez et al. 2000; and (7) Crotts et al. 1994.

sion, continuum, and intrinsic absorption characteristics. Component A shows strong BALs of C IV λλ1548, 1551 (∼6500–27,000 km s^{-1}), Si IV λ1400, N V λ1240, and O VI λ1034. The emission-line shapes, equivalent widths, and intensity ratios are different between components A and B.

The two components of other binary QSOs agree in emission-line redshift within about 600 km s^{-1} (Kochanek et al. 1999). For LBQS 0103−2753, the emission redshifts, $z_A = 0.834$ and $z_B = 0.858$, differ by 3900 km s^{-1}. The centroids of the C IV λ1549 emission-line profiles above 50% of peak flux level were used to measure the redshifts. The formal 1 σ errors in redshift for components A and B, in velocity units, are 370 and 210 km s^{-1} respectively, and the systematic errors, estimated from different choices for the continuum, are ±1000 and ±400 km s^{-1}, respectively. For component B, the Lyα line gives the same redshift as C IV. For component A, the Lyα and N V λ1240 emission lines are blended with an unknown ratio of line strengths and an uncertain profile because the N V BAL truncates the feature on the blue side. The Si IV and O IV] λ1400 and O VI λ1034 emission lines in component A, with positions marked in Figure 2 based on $z_A = 0.834$, are probably present but weak, and the wavelengths are uncertain because the shapes of the overall features are dominated by the adjacent BALs. The redshift of component A depends entirely on the measurement of the C IV line. However, C IV emission lines are often blueshifted from the systemic redshift (e.g., Espey et al. 1989), and weak low-contrast lines, like the C IV emission in A, tend to be shifted the most (Brotherton et al. 1994). If there was a large blueshift from the systemic value for A and little blueshift from the systemic value for B, the systemic redshifts could be close. Further observations are needed to determine the systemic redshift difference between A and B.

The optical spectrum of LBQS 0103−2753 (the summed components shown in Fig. 3) has undergone a large change in 11 yr in the observed frame or in 6 yr in the QSO frame. The Mg II λ2798 BAL, which is the strongest of the low-ionization BALs (Voit, Weymann, & Korista 1993), has changed from about 50% deep in 1987 to less than 10% deep in 1998. The spectrum of LBQS 0103−2753 obtained in 1998 August matches the average non-BALQSO spectrum (Weymann et al. 1991) to within 3% between λ2600 and the base of Mg II. Also, the continuum has apparently become bluer from 1987 to 1998. Low-ionization BALQSOs tend to have redder spectra than BALQSOs without low-ionization lines (Sprayberry & Foltz 1992). The STIS spectrum of LBQS 0103−2753, obtained about 11 months after the optical spectrum of 1998 August, shows very strong high-ionization BALs but no apparent low-ionization BALs like C II λ1335. In 6 yr in the QSO frame, LBQS 0103−2753A has changed from a low-ionization BALQSO to a high-ionization BALQSO. This is a large change compared with typical BALQSO variability (Barlow 1993). The unusual BAL variability was noted (Junkkarinen, Cohen, & Hamann 1999) before the STIS observations were obtained that show LBQS 0103−2753 is a binary QSO.

If we assume power-law continua $F_\lambda = F_0(\lambda/\lambda_0)^p$ for each component, with $\lambda_0 = 5700$ Å, the flux ratios of A and B at λ3000 (STIS) and λ7230 (image) give $F_A/F_B = 3.0(\lambda/\lambda_0)^{0.2}$, so that B is slightly bluer than A. Using the CTIO fluxes at 4150 and 5700 Å, we find that $p_A, p_B = -0.66, -0.86$ and $F_{0,A}, F_{0,B} = 2.4, 0.81$ in units of 10^{-16} ergs s^{-1} cm^{-2} Å^{-1}. Extrapolating the observed spectra to $5500(1+z)$ Å, we find that components A, B have absolute magnitudes $M_V = -26.0$, -24.6, again for $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

4. DISCUSSION

The odds of finding two unrelated QSOs so close in direction and redshift are negligible. The very different ultraviolet spectra of LBQS 0103−2753A and B show that this is a true binary, not a lensed QSO. Variability, microlensing, and differential reddening might give different spectra or colors for components of a lensed QSO. However, for our pair, the expected time delay for a lens is ∼10 days, and luminous QSOs rarely show significant variability over such times. Unequal reddening cannot explain the different absorption and emission lines of LBQS 0103−2753A and B (see Lopez, Hagen, & Reimers 2000 for a related discussion).

What is the rate of occurrence of such close binary QSOs? The *HST* snapshot survey for gravitationally lensed QSOs observed 498 QSOs with $z > 1$ and $M_V < -25.5$ ($H_0 = 100$, $q_0 = 0.5$; Maoz et al. 1993 and references therein). No binary QSOs with separations less than 1″.0 were found. Our pair slightly misses the redshift cutoff for the snapshot survey, but the angular diameter distance is not a strong function of redshift above $z = 0.86$ (see Hogg 1999 and references therein). LBQS 0103−2753 also misses the absolute magnitude cutoff by ∼0.6 mag. However, with regard to angular separation and magnitude difference, the snapshot survey provides some guidance. At a separation of 0″.3, the snapshot survey could detect pairs with a magnitude difference ≤1.5 at a P.A. of 0° relative to the image trail, the least favorable P.A. for detection (Bahcall et al. 1992). A pair with the spacing and magnitude difference ($\Delta m_V = 1.2$) of LBQS 0103−2753 should have been detected at any P.A. If the snapshot survey accounts for most of the opportunities to detect such a pair to date, the example of LBQS 0103−2753 is consistent with a rate of roughly 1/500 for separations of ∼0″.3. Among the ∼10^4 known QSOs, there likely are of order 10 unrecognized binaries in the 0″.3 range.

Is LBQS 0103−2753 likely to be a chance projection of a wider binary? The probability of a QSO having a binary companion at 3″–10″ is ∼$10^{-2.7}$ (Djorgovski 1991; Kochanek et al. 1999 and references therein). The cases listed by Kochanek et al. have a median separation of ∼5″ (40 kpc). The probability that a pair with this physical spacing will have a projected spacing of 0″.3 or less, because it is oriented nearly along the line of sight, is (coincidentally) ∼$10^{-2.7}$. The probability that a randomly selected QSO will be such a pair, and that it will be so oriented, is then $10^{-2.7} \times 10^{-2.7} = 10^{-5.4}$. Then, in a sample of 500 QSOs, the probability of finding even one pair at 0″.3 is only ∼$10^{-2.7}$. This suggests that LBQS 0103−2753 is not a chance projection of an ∼40 kpc binary but rather has a true spacing not much greater than 2 kpc.

Close binary QSOs presumably represent mergers of galaxies in which the nuclei in both galaxies are currently active. Observations of nearby galaxies show that the nuclei of large galaxies typically contain supermassive black holes (e.g., Kormendy & Richstone 1995). The merger will likely produce a supermassive binary black hole (Begelman, Blandford, & Rees 1980). Simulations of colliding disk galaxies by Barnes & Hernquist (1996) show little perturbation of the incoming galaxies until the first pericenter passage. However, gas accumulates in the nucleus of each galaxy as the two orbit away from each other. The time to orbit to an apocenter of ∼40 kpc and fall back is ∼$10^{8.5}$ yr for galactic masses relevant here (see below). Subsequent orbital loops are much smaller, and the central regions of the galaxies merge quickly, entailing a massive concentration of gas in the nucleus. We speculate that the observed 3″–10″ binary QSOs mostly represent galaxy pairs undergoing the loop following the first close encounter and that LBQS 0103−2753 is in a later stage when the nuclei of the two galaxies are coalescing.

Is the incidence of 0″.3 binaries consistent with this scenario? The time for the orbit to decay from radius R to the center by dynamical friction is $t_{\rm df} \approx (10^{8.6}\ {\rm yr})(R/2\ {\rm kpc})^2 M_8^{-1} \sigma_{200}$ (Binney & Tremaine 1987; Mortlock et al. 1999 and references therein). Here M_8 is the mass of the orbiting black hole (in units of $M/10^8\ M_\odot$), which is assumed to be the smaller hole on a circular orbit through the stellar background of the larger galaxy (with a velocity dispersion of $\sigma_{200} \equiv \sigma/200\ {\rm km\ s^{-1}}$). Let us assume that each QSO is shining at one-third of the Eddington limit (see Kaspi et al. 2000) and take $L_{\rm bol} \approx 8.3\lambda L_\lambda(3000\ Å)$ following Laor (1998). Then $L_{\rm bol} \approx 10^{46.6}, 10^{46.1}$ for A, B; the black hole masses are $M_{\rm A}, M_{\rm B} \approx 10^{9.0}, 10^{8.5}$. The recently discovered correlation of black hole mass with bulge velocity dispersion, $M_{\rm BH} = (10^{8.1}\ M_\odot)\sigma_{200}^{3.75}$ (Gebhardt et al. 2000; Ferrarese & Merritt 2000), gives $\sigma_{\rm A}, \sigma_{\rm B} = 350, 260\ {\rm km\ s^{-1}}$. The total bulge mass should be ∼$500 M_{\rm BH}$ (Kormendy & Richstone 1995). Tidal radius considerations suggest that the dense core of the stellar nucleus of galaxy B remains intact around black hole B, with a total mass of ∼$10^{10}\ M_\odot$. This shortens the dynamical friction time, and the above formula then suggests that the orbit decays on a dynamical timescale of ∼10^7 yr. The discovery of LBQS 0103−2753 then indicates that the probability of both nuclei being active as QSOs during the 2 kpc stage of a merger is ∼$10^{1.5}$ times higher than during the 40 kpc phase. Simulations of galactic mergers, including supermassive black holes, could help us clarify these timescales.

Ultraluminous infrared galaxies ($L_{\rm ir} > 10^{11}\ L_\odot$) typically involve mergers, the mean nuclear spacing being ∼2 kpc (Sanders & Mirabel 1996; Genzel & Cesarsky 2000). For high luminosities, the predominant power source appears to be the active galactic nucleus activity that is heavily obscured by a large mass of nuclear gas and dust. From this perspective, an important aspect of LBQS 0103−2753 is the lack of heavy extinction, perhaps because the high QSO luminosity has dispersed the nuclear gas. Infrared observations of LBQS 0103−2753 would be most interesting, as would observations that could detect a large mass of atomic or molecular gas expanding away from the nucleus.

The discovery of LBQS 0103−2753 suggests that binaries with separations of several kiloparsecs occur with a frequency on the order of one or two per thousand QSOs. The detection of just a few more cases would provide a better estimate of this rate, providing an important constraint on galactic mergers and the fueling of active galactic nuclei.

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