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A *HUBBLE SPACE TELESCOPE* FAINT OBJECT SPECTROGRAPH SURVEY FOR BROAD ABSORPTION LINES IN A SAMPLE OF LOW-REDSHIFT WEAK [O III] QUASI-STELLAR OBJECTS[1]

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ABSTRACT

The study by Boroson & Meyers led to the suggestion that radio-quiet QSOs with weak [O III] and strong Fe II emission spectra form a class of QSOs that has a high probability of exhibiting broad absorption lines (BALs) in their spectra. Furthermore, they argued that since narrow-line [O III] emission is almost certainly emitted isotropically, this indicates that such objects have relatively large BAL region covering factors. Low covering factor models are consistent with scenarios in which most QSOs have BAL regions, while higher covering factor models are consistent with scenarios in which there are special classes of QSOs with large BAL region outflows. By making *Hubble Space Telescope* (*HST*) FOS observations and using *IUE* or *HST* archival data when available, the details of the Boroson & Meyers suggestion have been explored by directly searching for classical C IV BALs in a sample of 18 QSOs with weak [O III] and often strong Fe II emission. Six of the 18 QSOs are found to exhibit C IV BALs. (In the archival sample, four of six objects have BALs, while two of the 12 new objects observed with the *HST* FOS have BALs.) However, there is evidence that the sample is heterogeneous, with *IRAS*-selected objects and high-luminosity objects having a greater tendency to exhibit BALs. If an isotropic model for [O III] emission equivalent width is considered, the results suggest that for the 18 object sample as a whole the average BAL region covering factor is $\approx 0.33^{+0.20}_{-0.09}$, which is significantly larger (with a more than 99% probability) than the overall fraction of QSOs observed to have BALs (normally taken as ≈ 0.1). Given possible selection effects, in the context of an isotropic model the results may indicate that some of the sample objects have covering factors $\ll 0.33$, while others have covering factors $\gg 0.33$. At the same time, it is impossible to rule out in a non–model-dependent way a scenario in which orientation effects are important and covering factors are generally small. Results such as these ultimately provide constraints on QSO geometries, intrinsic QSO properties, and evolutionary processes in QSOs.

Subject headings: galaxies: structure — quasars: absorption lines — quasars: emission lines

1. INTRODUCTION

The broad absorption line (BAL) phenomenon that is observed in QSO spectra may be representative of viewing angle dependencies, intrinsic QSO properties, and/or evolutionary processes in QSOs. A fundamental question is: what fraction of the sky do the BAL clouds cover as viewed from the central source, or, in other words, what is the BAL region covering factor? Some of the most recent results on BAL region covering factors are by Boroson & Meyers (1992), Hamann, Korista, & Morris (1993), and Turnshek et al. (1994). For additional background discussion, see Turnshek et al. (1994 and references therein) and Turnshek 1988, 1995). The Hamann et al. (1993) work, which is based on resonance line scattering models, is consistent with and reinforces past work that indicates that BAL region covering factors are often less than 0.2 (Turnshek et al. 1980; Junkkarinen, Burbidge, & Smith 1983). Based on an entirely different approach, however, Boroson & Meyers (1992) conclude that there is a special class of QSO that is representative of QSOs with large BAL region covering factors. From optical studies of low-redshift objects, they find that radio-quiet QSOs with weak narrow-line [O III] emission and strong Fe II emission have a high probability of having low-ionization BALs. However, the "BALs" detected by Boroson & Meyers (1992) were the result of very weak Na I D and/or Mg II, and not the classical high-ionization C IV BALs that are normally used to identify BAL QSOs. In any case, Boroson & Meyers (1992) conclude that since narrow-line [O III] emission is almost certainly emitted isotropically, QSOs with these characteristics have large BAL region covering factors, possibly approaching unity. More recently, the study of Q0043+0354 by Turnshek et al. (1994) concluded that this object is likely to have a large BAL region covering factor. It is important to keep in mind, however, that even if the emission flux of [O III] is isotropic, the continuum emission may not be, and this would affect the [O III] equivalent width. The study we present here should be considered primarily an empirical one, and any conclusions that can be made about the BAL region covering factor will be model dependent.

We have made *HST* FOS observations—and used *IUE* and *HST* archival data when available—of a sample of weak [O III] QSOs with generally strong Fe II emission to search for the classical C IV BALs in order to elucidate some of these earlier results. We find a high incidence of C IV BALs in the weak [O III] sample, as well as other interesting trends. In § 2, we define the sample and present the UV

[1] Based on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

TABLE 1

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QSO	m_B	z_{EM}	Observation Mode	Observation Date	Integration Time (s)
0003+0146......	16.6	0.234	*HST*-FOS-G190H	1994 Jul 21	1380
0017+0209......	17.6	0.401	*HST*-FOS-G190H	1994 Jun 08	1794
0043+0354......	15.9	0.384	*HST*-FOS-G190H[a]	1991 Oct 28	2630
0759+6508......	14.5	0.148	*IUE*-SWP40376[a]	1990 Dec 17	13200
			IUE-SWP37199[a]	1989 Sep 28	12840
1121+4216......	16.0	0.234	*HST*-FOS-G190H	1994 Nov 22	792
1132−0302......	17.1	0.237	*HST*-FOS-G190H	1994 Nov 10	2004
1138+0204......	17.7	0.383	*HST*-FOS-G190H	1994 Nov 10	2070
1144−0115......	18.2	0.382	*HST*-FOS-G190H	1994 Jun 27	3282
1214+1804......	16.8	0.375	*HST*-FOS-G190H	1994 Jun 28	930
1311+0217......	16.9	0.306	*HST*-FOS-G190H	1994 Jun 27	1380
1317−0142......	17.3	0.225	*HST*-FOS-G190H	1994 Jul 15	2784
1340−0038......	17.1	0.325	*HST*-FOS-G190H	1994 Jul 22	1380
1402+2609......	15.6	0.164	*HST*-FOS-G190H	1994 Jun 08	702
1402+4341......	16.5	0.323	*HST*-FOS-G190H	1994 Jul 17	978
1415+4509......	15.7	0.114	*IUE*-SWP25885[a]	1985 May 08	22800
			IUE-SWP25892[a]	1985 May 09	23700
1444+4047......	16.0	0.267	*HST*-FOS-G190H[a]	1992 Sep 05	3380
1552+0831......	16.0	0.119	*IUE*-SWP28237[a]	1986 Apr 28	10200
1700+5153......	15.4	0.290	*HST*-FOS-G190H[a]	1993 Mar 10	2026

[a] Archival.

spectral observations. In § 3, we summarize some of the sample's properties, including the results of the search for BALs. In § 4, we discuss the implications of these findings.

2. DEFINITION OF THE OBSERVED SAMPLE AND OBSERVATIONS

We investigated a sample that was drawn from the small but relatively bright optical samples studied by Boroson & Green (1992) and Boroson & Meyers (1992), as well as from the Large Bright Quasar Survey (LBQS), Parts I–IV (Foltz et al. 1987, 1989; Hewitt et al. 1991; Chaffee et al. 1991). Using the QSOs in these studies, we defined a sample of radio-quiet QSOs by first limiting the redshift range to $z_{EM} \lesssim 0.4$, so that the absence of narrow-line [O III] λ5007 emission and the presence of strong optical Fe II emission could be more easily studied with existing optical databases. We further limited the sample by selecting QSOs with narrow-line [O III] emission rest equivalent width $REW_{[O III]} \lesssim 5$ Å and magnitudes $B \lesssim 18.1$, where $B \equiv m_B$. These criteria result in a sample of objects that often have unusually strong optical Fe II emission, which is consistent with the findings of Boroson & Green (1992). Initially, a sample of 22 objects resulted from these selection criteria; however, we did not acquire data for four of the objects (Q0256−0034 with $B \approx 18.1$ and $z_{EM} \approx 0.36$; Q1129−0229 with $B \approx 17.7$ and $z_{EM} \approx 0.33$; Q1519+2238 with $B \approx 16.1$ and $z_{EM} \approx 0.14$; and Q1543+4845 with $B \approx 16.1$ and $z_{EM} \approx 0.40$). The exclusion of these four objects from the final sample was done without bias. Q0256−0034 was one of the faintest targets, and it was not scheduled for *HST* observation because of the time that was allotted for this program. An *HST* FOS G190H observation of Q1129−0229 was attempted, but evidently it failed during target acquisition, and the object has not been reobserved. Q1519+2238 is reported to have $REW_{[O III]} \approx 4$ Å by Boroson & Green (1992), but De Robertis (1985) earlier reported $REW_{[O III]} \approx 12$ Å; it was not scheduled for observation given this discrepancy and the limited *HST* time. Finally, Q1543+4845 lies at the upper redshift boundary of the sample, and it was also not observed because of the limited availability of *HST* time. However, it should be noted that the *IUE* spectrum of Q1543+4854 can be found in Lanzetta, Turnshek, & Sandoval (1993, hereafter LTS). While the signal-to-noise ratio of the spectrum is very poor, it appears somewhat absorbed, so the presence of BALs remains an open issue in this object.

The remaining 18 objects, as presented in Table 1, constitute the final sample. The observational program basically consisted of acquiring suitable data near the C IV λ1549 region, either by making *HST* FOS G190H observations or by obtaining available *HST* or *IUE* archival observations. For each object, Table 1 gives the QSO coordinate designation, the *B* magnitude, the emission redshift, and the *HST* FOS G190H journal of observations (or any archival data that were used instead). Five of the sample objects had existing *IUE* short-wavelength prime (SWP) archival spectra that were of sufficient quality to check for the presence of C IV BALs. These objects were Q0759+6508 (LTS; Hines & Wills 1995), Q1415+4509 (LTS), Q1444+4047 (LTS), Q1552+0831 (LTS), and Q1700+5153 (Turnshek et al. 1985; Pettini & Boksenberg 1985; LTS). Since Q1444+4047 and Q1700+5153 also had higher quality *HST* FOS G190H archival data, we used these data rather than the *IUE* data. Aside from Q1700+5153 and Q1444+4047, Q0043+0354 also had existing *HST* FOS G190H observations (Turnshek et al. 1994). For the remaining 12 objects, we obtained *HST* FOS G190H spectra using the integration times specified in Table 1, and this resulted in spectra with signal-to-noise ratios of ≈20–30. Figure 1 shows the UV spectra of the 18 objects in the region near C IV.

3. SAMPLE PROPERTIES

3.1. *Overall Results*

For the 18 objects in the final sample, we have compiled in Table 2 the spectral properties that were the focus of the investigation. Table 2 gives the following: $REW_{[O III]}$; an assessment of the REW of any optical Fe II emission,

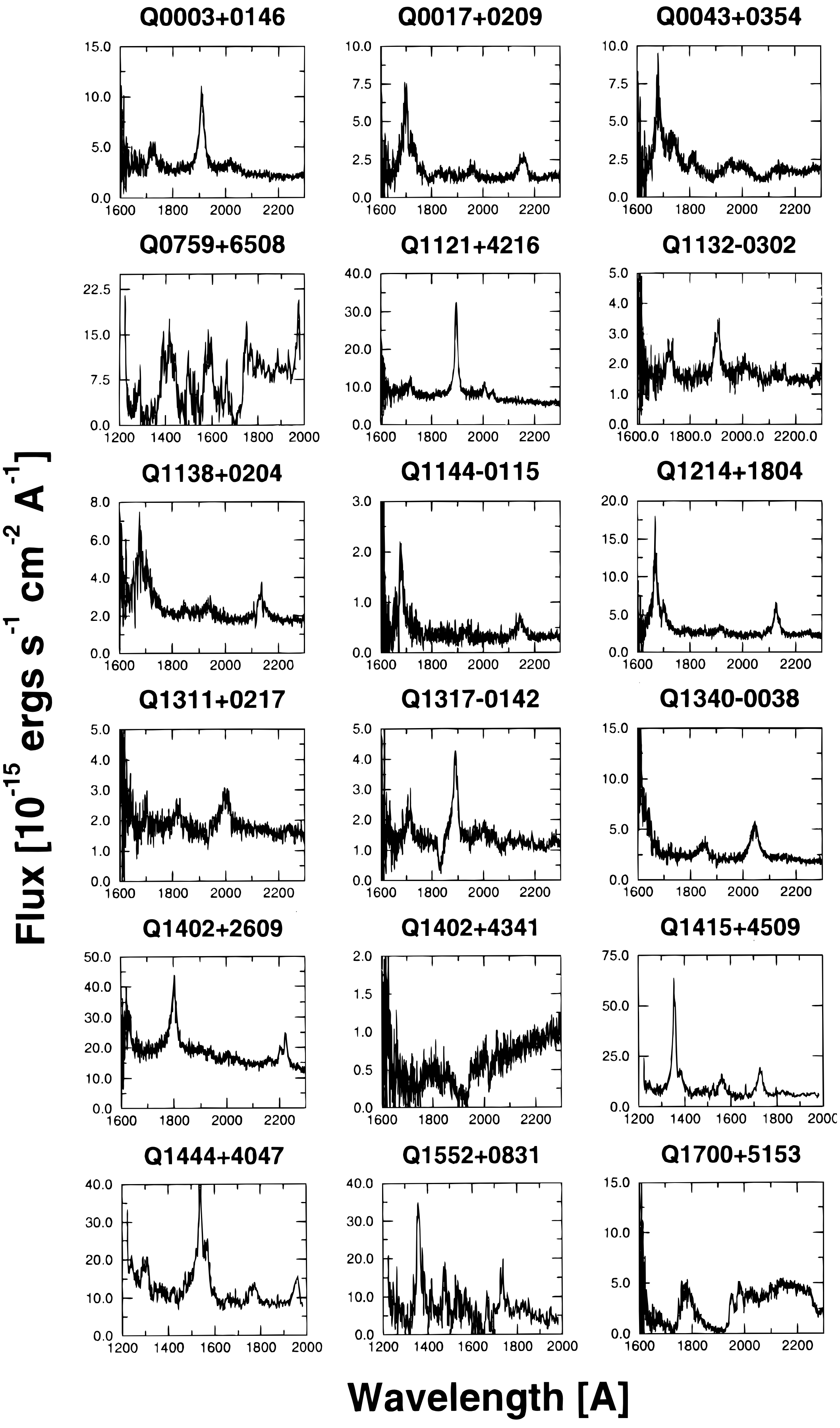

FIG. 1.—*HST* FOS G190H spectra (resolution $\lambda/\Delta\lambda \approx 1300$) or *IUE* SWP archival spectra (resolution $\lambda/\Delta\lambda \approx 250$) for the sample of weak [O III] QSOs

TABLE 2

MEASUREMENTS OF THE WEAK [O III] SAMPLE

QSO	m_B	z_{EM}	[O III] REW (Å)[a]	Fe II REW (Å)[a]	Mg II BAL?	C IV BAL?	log $L(B)$ ($L_\odot$)	log L(FIR) /$L(B)$	Reference
0003+0146......	16.6	0.234	4:	21:	?	no	11.03	<0.91	1, 2
0017+0209......	17.6	0.401	2:	108:	no	no	11.14	<1.29	2, 3
0043+0354......	15.9	0.384	1	109	no	yes	11.78	<0.61	4, 5
0759+6508......	14.5	0.148	0	134	yes	yes	11.47	0.85	6, 7
1121+4216......	16.0	0.234	5	33	?	no	11.28	<0.66	2, 4
1132−0302......	17.1	0.237	2:	47:	?	no	10.86	<1.09	2, 8
1138+0204......	17.7	0.383	2:	50:	?	no[b]	11.05	<1.34	2, 8
1144−0115......	18.2	0.382	3:	47:	no	no	10.84	<1.55	2, 8
1214+1804......	16.8	0.375	2:	19:	no	no	11.39	<0.98	2, 9
1311+0217......	16.9	0.306	2:	48:	no	no	11.16	<1.02	2, 8
1317−0142......	17.3	0.225	2:	47:	?	yes	10.71	<1.19	2, 8
1340−0038......	17.1	0.325	4:	86:	no	no	11.16	<1.16	2, 8
1402+2609......	15.6	0.164	1	94	no	no	11.13	<0.59	2, 4
1402+4341......	16.5	0.323	0	50	?[c]	yes	11.38	1.30	2, 6
1415+4509......	15.7	0.114	1	73	no	no	10.74	<0.55	4, 7
1444+4047......	16.0	0.267	1	104	no	no	11.42	<0.64	4, 10
1552+0831......	16.0	0.119	3	47	no	yes	10.67	<0.66	4, 7
1700+5153......	15.4	0.290	2	78	yes	yes	11.71	0.74	4, 6, 10

[a] The colon indicates greater uncertainty, since the rest equivalent width measurement was made graphically using the spectrum published in the literature.

[b] Contains associated $z_{abs} \approx z_{EM}$ absorption.

[c] Low et al. 1989 reported Mg II BALs, but this was not confirmed from inspection of the De Grijp et al. 1992 spectrum.

REFERENCES.—(1) Chaffee et al. 1991; (2) this study; (3) Foltz et al. 1989; (4) Boroson & Green 1992; (5) Turnshek et al. 1994; (6) Boroson & Meyers 1992; (7) LTS; (8) Hewett et al. 1991; (9) Foltz et al. 1987; (10) *HST* archives.

$\mathrm{REW}_{\mathrm{opt-Fe\,II}}$, as defined using the technique adopted by Boroson & Green (1992); the results of searches for both C IV BALs and Mg II BALs (when possible); the estimated optical (*B*-band) luminosity, $L(B)$; measurements or upper limits on the far–infrared-to-optical flux ratio as estimated from *IRAS* data, $L(\mathrm{FIR})/L(B)$; and references to spectral data. Note that Weymann et al. (1991) gives a working definition for a spectrum that exhibits BALs, and we have followed that definition. The optical (*B*-band) luminosities, $L(B)$, were calculated using *B* magnitudes when available or photographic B_J magnitudes from the LBQS, assuming $B_J = B - 0.28(B-V)$ (Blair & Gilmore 1982), where $B-V$ was taken to be ≈ 0.3. The flux per unit frequency interval in the *B* band, $f_\nu(B) = 10^{-0.4(B+48.36)}$ ergs cm^{-2} s^{-1} Hz^{-1} (Schmidt & Green 1983), was used to calculate the luminosity per unit frequency interval near *B*, $L_\nu(B)$, assuming $q_0 = 0.5$ and $H_0 = 50$ km s^{-1} Mpc^{-1}. The total *B*-band luminosity was determined from the expression $L(B) = \Delta\nu_B L_\nu(B)$, where the width of the *B* filter passband was taken as $\Delta\nu_B = 1.6 \times 10^{14}$ Hz. Table 2 lists the values of log $L(B)$ in units of $L_\odot$ for the 18 QSOs in the sample. We have adopted the definition of Helou et al. (1988) to estimate the far-infrared (FIR) flux in the vicinity of the 60 and 100 μm *IRAS* bands: $\Delta\nu_{\mathrm{FIR}} f_\nu(\mathrm{FIR}) = 1.26 \times 10^{-14}[2.56 f_\nu(60\ \mu\mathrm{m}) + 1.00 f_\nu(100\ \mu\mathrm{m})]$ ergs cm^{-2} s^{-1}, where $f_\nu(60\ \mu\mathrm{m})$ and $f_\nu(100\ \mu\mathrm{m})$ are in Jy. The far-infrared luminosity in these bands, $L(\mathrm{FIR})$, was then calculated assuming the same cosmology adopted above. Finally, the references to Table 2 include the source of the optical spectrum that resulted in the selection of the object for the weak [O III] sample, as well as any existing data that were used.

As could be gleaned from the discussion in § 2 and Table 2, it is possible to divide the 18 object sample into an archival sample of six objects (Q0043+0354, Q0759+6508, Q1415+4509, Q1444+4047, Q1552+0831, and Q1700+5153), for which data were already available, and the newly observed *HST* sample of 12 objects. Four of six objects (67%) in the archival sample have BALs, while only two of 12 objects (17%) in the new sample have BALs. With some exceptions, but as might generally be expected, the archival sample tends to contain more luminous objects and *IRAS*-selected objects than the new sample. Thus, there is evidence that the sample is heterogeneous, with *IRAS*-selected objects and high-luminosity objects having a greater tendency to exhibit BALs.

Taking the results that pertain to the sample as a whole, we therefore find that six of 18 spectra show C IV BALs (see Table 2). Thus, for the defined selection criteria, which require objects to be radio-quiet QSOs with $\mathrm{REW}_{[\mathrm{O\,III}]} \lesssim 5$ Å, we find that the fraction of objects with C IV BALs in their spectra is $f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} \leq 5\ \text{Å}) = 0.33^{+0.20}_{-0.09}$ (1 σ errors, indicative of the 68% probability interval). This fraction is significantly larger than the overall fraction of QSOs observed to have BALs, which is taken to be 0.1 (e.g., Weymann et al. 1991). The difference is significant at more than 99% probability, assuming that the overall fraction of 0.1 is fixed and well known (see also the later discussion in § 4.2, where we argue that f_{BALs} in a strong [O III] sample must be smaller, making the difference even more significant). In addition, 12 of the objects have data of sufficient quality in the vicinity of Mg II to show that two of them have Mg II BALs. (Note that two of the six objects with insufficient data to search for Mg II have C IV BALs. As discussed in the next paragraph, it is possible that at least one of these objects, Q1402+4341, has Mg II BALs—but the spectrum is unpublished and so we do not assume this.) Therefore, the fraction of low-ionization Mg II BAL QSOs in a subsample of 12 objects for which this can be checked is $f_{\mathrm{Mg\,II-BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} \leq 5\ \text{Å}) = 0.17^{+0.22}_{-0.05}$. Since past studies show that $\approx 10\%$ of the BAL QSOs have low-ionization BALs (in our sample two of four BAL QSOs for which the presence of Mg II BALs could be reliably checked have Mg II BALs), we can estimate that the fraction of QSOs with low-ionization BALs is $\approx 0.1 \times 0.1 = 0.01$. Thus, to a high level of confidence (again, >99% probability) we conclude that a weak [O III] selected sample of QSOs also shows a high incidence of low-ionization Mg II BALs. Again, we want to emphasize that there is some evidence that our sample is heterogeneous and that division of a larger sample based on luminosity or IR properties might reveal subsamples with both $f_{\rm BALs} \gg 0.33$ and $f_{\rm BALs} \ll 0.33$. Some additional discussion is made below for the purpose of clarification.

It should be mentioned again that our particular sample was restricted to be of low redshift, $z_{\rm EM} \lesssim 0.4$, so that [O III] λ5007 and optical Fe II emission would be easily accessible in ground-based spectra. The absolute magnitudes of the sample objects (all QSO-like) were in the range $-23.4 \geq M_B \geq -26.1$, assuming $H_0 = 50$ km s^{-1} Mpc^{-1}. Figure 2 shows the far–infrared-to-optical flux ratio, L(FIR)/L(B), versus the optical (B-band) luminosity, L(B), for the sample (see also the text below and Table 2 for a discussion of errors and upper limits). A representative $\pm 20\%$ error in the value of L(B) for all the QSOs is indicated on the right-hand side of Figure 2, but it is not shown explicitly for each point. This representative error in L(B) is not included in the error for the L(FIR)/L(B) ratio. As was pointed out earlier, the three most luminous objects in the sample in terms of L(B) are BAL QSOs (Q0043+431, Q0759+6508, and Q1700+5153), suggesting that the more luminous objects are more likely to have BALs. If these three objects are eliminated, the fraction of QSOs with BALs is much smaller (i.e., only three out of 15 objects or 20% have BALs). (However, it might also be argued that such luminosity-dependent statistics should be considered somewhat biased, since they were calculated a posteriori.) While all the objects in the present sample have QSO-like luminosities, it is worth noting that Turnshek & Grillmair (1986) have reported that objects with Seyfert-like luminosities appear to lack bona fide BALs indicative of high-velocity outflows.

In addition, three QSOs in our final sample of 18 objects (Q0759+6508, Q1402+4341, and Q1700+5153) were present in the *IRAS* Point Source Catalog (1988) in both 60 and 100 μm bands, and all of these are BAL QSOs (two of these were also in the very luminous category discussed above); no other objects in our sample were found in the Point Source Catalog. Two non-BAL QSOs (Q1402+2609 and Q1340−0038) do not appear in the Point Source Catalog but are listed as detections at 60 μm with a high enough signal-to-noise ratio to include them in the *IRAS* Faint Source Catalog (1990). The 100 μm fluxes of these two objects must be $\lesssim$0.5 Jy. The 13 remaining objects were not listed in either the *IRAS* Point or Faint Source Catalogs. For these QSOs, upper limits on L(FIR) were calculated using the $\approx$0.2 Jy flux threshold at 60 μm to evaluate inclusion of sources in the *IRAS* Faint Source Catalog. Again, a value of 0.5 Jy was taken as an upper limit on the possible flux in the 100 μm band, although the uncertainty for detection in this band is more pronounced as a result of the infrared cirrus and therefore this flux is not a criterion used for inclusion of sources in the Faint Source Catalog (Moshir et al. 1992). Error bars are included for the *IRAS* Point Source Catalog objects and represent the uncertainty in L(FIR) due to 1 σ errors in the 60 and 100 μm fluxes. For the two cases in which there was a flux detection at 60 μm but the 100 μm flux was an upper limit, the error in L(FIR) was derived using the 1 σ error in the 60 μm flux and assuming that the value at 100 μm could lie anywhere between no flux and 0.5 Jy. At least two of the three *IRAS* Point Source Catalog objects (i.e., Q0759+6508 and Q1700+5153, which are in the very luminous category) exhibit Mg II BALs, and Low et al. (1989) report that the third object (Q1402+4341) also has Mg II BALs. Therefore, as suggested earlier, the results show a tendency for the low-ionization BAL QSOs in the sample to be strong *IRAS* sources (see § 3.2 for comments on individual objects). This is consistent with the results of Low et al. (1988), as derived from a study of the Warm Extragalactic Object (WEO) sample. Note that to calculate the statistics presented in this study, we did not assume that Mg II BALs were present in the spectrum of Q1402+4341, as reported by Low et al. (1989). The Low et al. spectrum is unpublished, and confirmation of the presence of Mg II BALs in Q1402+4341 is needed because a depression on the short-wavelength side of the Mg II broad emission line is created when strong UV Fe II emission is present, and this is sometimes mistaken for a weak Mg II BAL. We note that the spectrum of Q1402+4341 by De Grijp et al. (1992) does not appear to show a Mg II BAL, but the behavior of the near-UV part of the spectrum is not clear enough to be certain.

Finally, in the weak [O III] selected sample itself, there seems to be no particularly significant trend indicating that QSOs with the weakest [O III] emission have stronger Fe II emission. In particular, the six BAL QSOs in our sample have $\langle {\rm REW}_{\rm [O\,III]} \rangle \approx 1.3 \pm 0.5$ Å and $\langle {\rm REW}_{\rm opt-Fe\,II} \rangle \approx 78 \pm 15$ Å, while the 12 non-BAL QSOs in our sample have $\langle {\rm REW}_{\rm [O\,III]} \rangle \approx 2.4 \pm 0.4$ Å and $\langle {\rm REW}_{\rm opt-Fe\,II} \rangle \approx 61 \pm 9$ Å. Any hint of an anticorrelation between ${\rm REW}_{\rm [O\,III]}$ and ${\rm REW}_{\rm opt-Fe\,II}$ is not particularly significant in our sample. On the other hand, in a sample showing a much larger range in ${\rm REW}_{\rm [O\,III]}$ and ${\rm REW}_{\rm opt-Fe\,II}$, Boroson & Green (1992) have convincingly showed that an anticorrelation is present between these two parameters.

3.2. *Comments on Objects with BALs*

Here we wish to comment briefly on the six objects that were found to exhibit BALs in their spectra. Q1138+0204 appears to have some associated ($z_{\rm abs} \approx z_{\rm EM}$) absorption in its spectrum. Having adopted the definition of Weymann et al. (1991), we do not consider this type of absorption to be BAL-like for the purposes of this study; however, this could be a related phenomenon.

Q0043+0354.—This object was recently studied extensively by Turnshek et al. (1994) as part of the *HST* QSO Absorption Line Key Project. It exhibits a very weak C IV BAL—so weak, in fact, that it might easily be missed in a low signal-to-noise spectrum (e.g., see the *IUE* data on this object in the atlas of LTS). Nevertheless, the object is extraordinary because its spectrum is also consistent with the presence of extremely strong UV Fe II emission and a reddening of $E(B-V) \approx 0.1$. Despite the probable reddening, there is no indication of a Mg II BAL. It is possible that the host galaxy might give rise to the reddening. The possible importance of orientation effects, which might lessen the need for reddening, was also discussed by Turnshek et al. (1994). In any case, the unique spectrum, coupled with the presence of BALs, led Turnshek et al. (1994) to suggest that the object has a large BAL region covering factor in a scenario that required the [O III] emission equivalent width to be isotropic (see also Boroson & Green 1992). This object does not appear in the *IRAS* Point

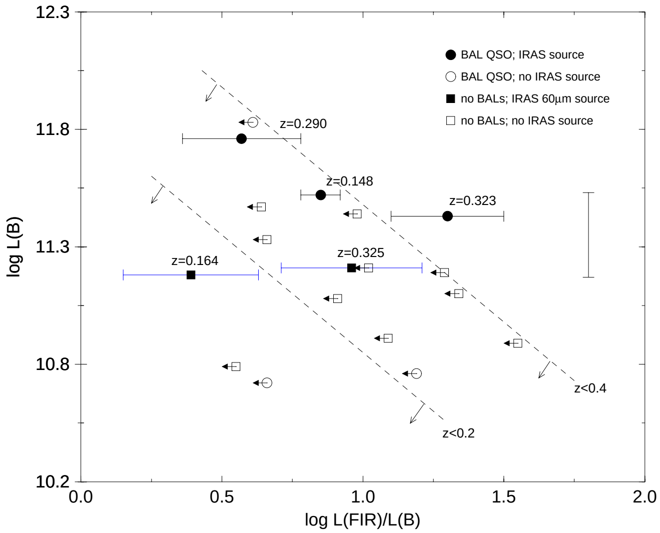

FIG. 2.—L(FIR)/L(B) flux ratio vs. optical (B band) luminosity, L(B), for the sample of weak [O III] QSOs. A description of how the luminosities, errors, and upper limits were computed is given in the text. Redshifts are labeled only for objects detected with *IRAS*. Two diagonal lines show the *IRAS* detection thresholds for objects of a given L(FIR) and L(B) for redshifts of $z_{\rm EM} \approx 0.4$ and 0.2.

Source or Faint Source Catalogs; it is one of the higher redshift objects in the sample.

Q0759+6508.—This object has recently been studied extensively by Hines & Wills (1995), it appears in the *IRAS* Point Source Catalog, is one of the objects in the Low et al. (1988) WEO sample (see also Low et al 1989), and is one of the objects in the Boroson & Meyers (1992) sample. It has a strong Mg II BAL, as well as strong high-ionization BALs, and its far-UV spectrum appears to be redder than is typical for a high-ionization BAL QSO (for presentation of comparison composite spectra, see Weymann et al. 1991; Sprayberry & Foltz 1992; Turnshek et al. 1994). Hines & Wills (1995) report that $E(B-V) \approx 0.12$ for the spectral energy distribution of the continuum, and they suggest that the Hα/Hβ emission-line ratio must be even more reddened with $E(B-V) \approx 0.45$. The spectropolarimetry of Hines & Wills (1995) shows that a Na I BAL appears in the unpolarized light spectrum but is absent in the polarized light spectrum, suggesting that there are some sight lines toward this object that are not obscured by outflowing Na I BAL material.

Q1317−0142.—This object is included in the sample because it is one of the LBQS objects that meets the selection criteria for weak [O III] emission. The *HST* FOS G190H observation presented here of a C IV BAL in its spectrum marks the first identification of this object as a BAL QSO. This object does not appear in the *IRAS* Point Source or Faint Source Catalogs; it is one of the optically fainter objects in the sample.

Q1402+4341.—This object is also in the *IRAS* Point Source Catalog, appearing as part of the Low et al. (1988) WEO and Boroson & Meyers (1992) samples. Once again, the *HST* FOS G190H observation presented here of a C IV BAL in its spectrum is the initial report of this identification. As discussed in § 3.1, it is unclear if a Mg II BAL is present in its spectrum (see, e.g., Low et al. 1989; De Grijp et al. 1992). The spectrum is clearly redder than a composite high-ionization BAL QSO spectrum.

Q1552+0831.—This object is also included in the sample because it is one of the LBQS objects that meets the selection criteria for weak [O III] emission. While the report here of a C IV BAL in its spectrum marks the first formal report of this identification, the spectrum did appear in the *IUE* atlas of LTS, and it is clear from the spectrum published in the atlas that a C IV BAL is present (see also Boroson & Green 1992). This object does not appear in the *IRAS* Point Source or Faint Source Catalogs; it is one of the optically fainter objects in the sample.

Q1700+5153.—The spectrum of this object has been studied by Wampler (1985), Turnshek et al. (1985), Pettini & Boksenberg (1985), Boroson & Green (1992), and Boroson & Meyers (1992). More recently, the object has been observed with the *HST* FOS. It appears in the *IRAS* Point Source Catalog and is one of the objects in the Low et al. (1988) WEO sample (see also Low et al. 1989) as well as the Boroson & Meyers (1992) sample. It has a moderately strong Mg II BAL and strong high-ionization BALs. The spectrum appears to look redder than the composite high-ionization BAL QSO spectrum.

4. DISCUSSION

4.1. *Connections to Earlier Results*

The abnormally high incidence of BALs in the spectra of radio-quiet weak [O III] QSOs found in this study is of course not the only systematic effect associated with the BAL phenomenon. The most dramatic effect identified so far is clearly the *lack of BALs* in the spectra of radio-loud quasars (Stocke et al. 1992). The reason for this absence is unknown. The radio results could be taken either as evidence for a class of QSOs with very small or zero BAL covering factor or cases in which radio emission is beamed in directions anticorrelated with BAL outflows. Under the right physical conditions, free-free absorption from gas associated with the BAL region would offer another mechanism for obscuring an inner compact radio source, but it has not been possible to observationally find evidence for this. A clue to understanding the observational results in the radio might be inferred from the recent finding that BAL QSOs tend to be very weak radio sources—clearly not classifiable as radio loud but often with higher radio-to-optical fluxes than " normal " radio-quiet non-BAL QSOs (Francis, Hooper, & Impey 1993). However, there is also no clear explanation for this latter effect.

Approximately 10% of the spectra of radio-quiet QSOs as a class exhibit BALs with outflow velocities typically ranging up to $\approx$10,000–30,000 km s^{-1}. The work on BAL QSOs that show only high-ionization BALs (e.g., C IV and N V) indicates that there are not many photons in the absorption/emission profiles that can be attributed to resonance line scattering of inner photons by the outflowing BAL clouds. Thus, in the absence of a viable mechanism for destroying the photons, this deficit of photons is taken to be evidence for BAL region covering factors that are *typically* less than 0.2 (Turnshek et al. 1980; Junkkarinen et al. 1983). More recently, however, Hamann et al. (1993) have done the most thorough and comprehensive analysis of resonance line scattering constraints on BAL region covering factors to date. Hamann et al. (1993) used resonance line scattering models to estimate the maximum BAL region covering factor in a sample of 40 moderate to high-redshift BAL QSOs. For a spherical scattering model, Hamann et al. report that either the shape of the C IV emission profile or the residual flux in the C IV BAL trough indicates that (reporting cumulative results) the covering factor must be $q_c \leq 0.1$ for 20% of the sample, $q_c \leq 0.2$ for 50% of the sample, $q_c \leq 0.3$ for 60% of the sample, and $q_c \leq 0.4$ for 70% of the sample. However, for 30% of the sample, $q_c > 0.4$ is possible. Of course, these constraints are limits and should only be considered illustrative since derivation of the true constraint depends on the scattering geometry that is largely unknown. The problem is also a statistical one in that the constraints become more powerful if they can be applied to a large sample of objects. Nevertheless, it is clear that BAL region covering factors in excess of ≈ 0.4 are permitted in a relatively large fraction of the objects. Furthermore, if some of the scattered photons are destroyed, constraints on the maximum covering factor are relaxed even further. In this respect, it is interesting to note that when Hamann et al. (1993) applied their spherical scattering model to Q0059−2735 they found that $q_c < 0.05$ was required to explain the absence of residual flux in the C IV BAL trough. However, this QSO is one of the low-ionization Mg II BAL QSOs that are prime candidate objects for having large BAL region covering factors in a scenario in which orientation effects are unimportant. As alluded to earlier, $\approx$10% of all BAL QSOs ($\approx$1% of all QSOs) may be of this low-ionization type. In the case of Q0059−2735 and similar cases, dust may act to destroy the resonance line scattered radiation, rendering the constraint on BAL region covering factor invalid. The large infrared-to-optical flux ratios and evidence for reddening in some of these objects (see, e.g., the discussion of Q0759+6508 and Q1700+5153 in § 3.2) are consistent with this interpretation.

Thus, the results presented here indicate that it is possible to use a well-defined set of optical/IR properties to select a sample of QSOs (even if it must include a special selection criterion for IR emission) that exhibits a significantly higher incidence of BALs than a radio-quiet sample as a whole. This finding is supported by earlier work (Boroson & Meyers 1992; Turnshek et al. 1994) and is not necessarily inconsistent with the models of Hamann et al. (1993). We demonstrated this in the present study using the equivalent width of the [O III] emission line as the selection criterion, finding that when $\mathrm{REW}_{[\mathrm{O\,III}]} \leq 5$ Å the fraction of QSOs with BALs is $f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} \leq 5\ \mathrm{Å}) \approx 0.33$. However, it is also apparent that such trends must be present to a lesser degree when other emission lines are taken as selection criteria. For example, the emission-line systematics discussed by Weymann et al. (1991) suggest that a sample of radio-quiet QSOs selected for having strong Fe II emission, strong N V emission, or even weak C IV emission would all yield samples that exhibited a somewhat higher incidence of BALs than is found in radio-quiet samples as a whole. This follows from the finding that, on average, Fe II and N V emission are stronger and C IV emission is weaker in a BAL QSO sample than in a non-BAL QSO sample. Therefore, we make the suggestion here that some advances in understanding the systematics of the BAL phenomenon might be made if we formulate the statistics on the presence of BALs in a new way. In particular, rather than report on the enhancement/weakness of a particular emission line in a sample of BAL QSOs in comparison to a sample of non-BAL QSOs, or report on a comparison of their composite spectra, it is likely to be more valuable quantitatively to specify how the probability of finding BALs depends on the equivalent width of certain emission lines or other properties. This type of formulation of the results has not been attempted in the past, but the investigation that has been made here based on the equivalent width of the [O III] emission line naturally lends itself to this type of analysis.

4.2. *Statistical Considerations*

To accomplish a more quantitative formulation we need to consider the statistical properties of the [O III] emission lines in the samples that were used to form our final weak [O III] sample. For the LBQS sample, there were a total of 54 radio-quiet QSOs with $z_{\mathrm{EM}} \lesssim 0.4$ and $B \lesssim 18.1$ that constituted an initial sample of QSOs for possible study. We determined that only 11 of these QSOs had $W_{[\mathrm{O\,III}]} \leq 5$ Å and we obtained UV observations for nine of them to search for BALs; the remaining 45 had $W_{[\mathrm{O\,III}]} > 5$ Å. Only one (Q1317−0142) of these nine weak [O III] LBQS QSOs had BALs. For the Boroson & Green (1992) sample there were a total of 68 radio-quiet QSOs with $z_{\mathrm{EM}} \lesssim 0.4$ and $B \lesssim 18.1$ that constituted an additional initial sample of somewhat more luminous QSOs for possible study. Only nine of these QSOs had $W_{[\mathrm{O\,III}]} \leq 5$ Å and we obtained UV observations of seven of them; the remaining 59 had $W_{[\mathrm{O\,III}]} > 5$ Å. Three (Q0043+0354, Q1552+0831, and Q1700+5153) of these seven weak [O III] QSOs had BALs. For the Boroson & Meyers (1992) IR-selected sample there were a total of six radio-quiet QSOs with $z_{\mathrm{EM}} \lesssim 0.4$ and $B \lesssim 18.1$ for possible study, but one of them lacked an [O III] measurement (Q1334+2438) and two others (Q1351+6400 and Q1700+5153) were already included in the Boroson & Green (1992) sample. Of the remaining three QSOs, two (Q0759+6508 and Q1402+4341) had $W_{[\mathrm{O\,III}]} \leq 5$ Å and both of these had BALs. Some details on references can be found in Table 2. In summary, the weak [O III] sample of 22 QSOs (only 18 observed) was drawn from a sample of 126 QSOs for which we had [O III] information, indicating that the weak [O III] property was found in $\approx$17% of the initial sample.

If we assume that the fraction of QSOs exhibiting BALS in radio-quiet QSO samples as a whole is $f_{\mathrm{BALs}} = 0.1$, then the result derived in this study that

$$f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} \leq 5\ \mathrm{Å}) = 0.33^{+0.20}_{-0.09} \quad (1)$$

implies that

$$f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} > 5\ \mathrm{Å}) \approx 0.05^{-0.04}_{+0.02} . \quad (2)$$

In addition, since $\langle \mathrm{REW}_{[\mathrm{O\,III}]} \rangle \approx 2$ Å in the weak [O III] sample and $\langle \mathrm{REW}_{[\mathrm{O\,III}]} \rangle \approx 28$ Å can be estimated for QSOs with $\mathrm{REW}_{[\mathrm{O\,III}]} > 5$ Å from the Boroson & Green (1992) results, we can estimate from the statistics that

$$\frac{df_{\mathrm{BALs}}}{d\mathrm{REW}_{[\mathrm{O\,III}]}} \approx 0.01\ \mathrm{Å}^{-1} . \quad (3)$$

Therefore, to first order,

$$f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]}) \approx 0.35 - 0.01\mathrm{REW}_{[\mathrm{O\,III}]} ; \quad \mathrm{REW}_{[\mathrm{O\,III}]} < 35\ \mathrm{Å} \quad (4)$$

and

$$f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]}) \approx 0 ; \quad \mathrm{REW}_{[\mathrm{O\,III}]} \geq 35\ \mathrm{Å} , \quad (5)$$

where $\mathrm{REW}_{[\mathrm{O\,III}]}$ is in units of Å.

At first, one might ask if these relationships are simply a natural consequence of the Baldwin Effect, since, as we mentioned in § 3.1, there may be a trend for BALs to be present in the spectra of the most luminous QSOs. However, Lee (1996) found the slope of the [O III] Baldwin Effect to be shallow ($\approx 0.19 \pm 0.05$) with considerable intrinsic scatter in $\mathrm{REW}_{[\mathrm{O\,III}]}$ at any given luminosity. Therefore, equations (1)–(5) should not be transformed into a luminosity parameterization. If this was the goal, it would be more appropriate to do this directly by observing f_{BALs} in subsamples spanning different luminosity intervals. In fact, with large enough samples it would be possible to form multiparameter distribution functions with parameters like z_{EM}, $L(B)$, $L(\mathrm{FIR})/L(B)$, REW_x, and FWHM_x, where x corresponds to a particular emission feature. This should be a future goal.

Several other clarifying points should also be made. Since UV spectra are not generally available for objects that formed the set of 126 objects from which the weak [O III] sample was derived, it is not possible to empirically derive $f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} > 5\ \text{Å})$. This is why we simply assumed $f_{\mathrm{BALs}} = 0.1$ above and then inferred $f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} > 5\ \text{Å})$ from the results on $f_{\mathrm{BALs}}(\mathrm{REW}_{[\mathrm{O\,III}]} \leq 5\ \text{Å})$. However, we do know of two objects that could be considered BAL QSOs that have $\mathrm{REW}_{[\mathrm{O\,III}]} > 5\ \text{Å}$. Q1351+6400 with $z_{\mathrm{EM}} = 0.090$ has $\mathrm{REW}_{[\mathrm{O\,III}]} = 31\ \text{Å}$ and $\mathrm{REW}_{\mathrm{opt-Fe\,II}} = 14\ \text{Å}$ (Boroson & Green 1992); its UV spectrum (LTS; Stocke et al. 1994) shows relatively narrow but nevertheless blueshifted BAL-like absorption in the wings of the adjacent emission lines. Q1351+6400 is also in the *IRAS* Point Source Catalog. Q1411+4414 with $z_{\mathrm{EM}} = 0.088$ has $\mathrm{REW}_{[\mathrm{O\,III}]} = 15\ \text{Å}$ and $\mathrm{REW}_{\mathrm{opt-Fe\,II}} = 51\ \text{Å}$ (Boroson & Green 1992); its UV spectrum (LTS; *HST* archives) is similar to the spectrum of Q1351+6400. Neither of these two objects is known to have low-ionization BALs. In terms of their BAL properties, the main notable difference between these two objects and the six objects that were part of the weak [O III] sample is their low maximum BAL outflow velocities of only a few thousand kilometers per second. In fact, there is probably some question as to whether they represent the same type of BAL phenomenon. In any case, it would be of interest to study empirically the incidence of BALs and the BAL properties in the much larger sample of 104 objects with $\mathrm{REW}_{[\mathrm{O\,III}]} > 5\ \text{Å}$.

4.3. *Interpretations*

How do we interpret these results? We will outline two extreme scenarios that might be considered when interpreting the observational results on QSOs/AGN and mention some approaches that might be taken to make future progress.

1. In one extreme scenario (e.g., consistent with unified models) we would assume that basically one type of object is being studied. The object would have the same intrinsic properties but would look different as a function of viewing angle. The inferred optical continuum luminosity and detailed shape of the continuum spectral energy distribution would depend on viewing angle. When viewed from the pole, we might see radio emission but we would never see BALs. When viewed from intermediate angles, we would see the characteristic emission lines in QSOs (e.g., for convenience we consider N V, Fe II, C IV, and [O III]) but we would seldom see BALs. When viewed from near edge-on angles, we would see some of the characteristic emission lines modified in strength (e.g., empirically, an acceptable model would have to give rise to stronger N V and Fe II emission equivalent widths but weaker C IV and [O III] emission equivalent widths) and we would often see BALs. The properties of the BALs might be modified by small changes in edge-on viewing angles. Viewing angles in radio-quiet directions that revealed significant optical polarization would also reveal the presence of BALs (see the recent studies of Hines & Wills 1995; Cohen et al. 1995; Goodrich & Miller 1995). Variations in emission-line profile shapes (kinematics) would also be of interest. Ideally, we would like to understand the constraints on covering factor that such a picture entails; however, such constraints are likely to be highly model dependent. More realistically, however, we might like to find independent evidence for such a model and have an understanding of the selection effects that might arise from it.

2. At the other extreme would be a scenario in which the observed incidence of BALs in different types of QSO spectra (e.g., those with weak [O III]) is an indication of BAL region covering factor. Spherical geometries would dominate, the continuum and line emission would be approximately isotropic, and viewing angle effects would be minimal. Ideally, the probability of seeing BALs would depend only on the BAL region covering factor and not on any viewing angle. Differences in QSO continuum and emission-line properties, and the presence of BALs with different types of characteristics, would be an indication of differences in the intrinsic properties of QSOs, including possible evolutionary stages. In this case, the results of this investigation could be taken as a constraint on the BAL region covering factor, q_c, i.e.,

$$q_c(\mathrm{REW}_{[\mathrm{O\,III}]}) \approx 0.35 - 0.01\mathrm{REW}_{[\mathrm{O\,III}]}\ ; \quad \mathrm{REW}_{[\mathrm{O\,III}]} < 35\ \text{Å} \tag{6}$$

and

$$q_c(\mathrm{REW}_{[\mathrm{O\,III}]}) \approx 0\ ; \quad \mathrm{REW}_{[\mathrm{O\,III}]} \geq 35\ \text{Å}\ . \tag{7}$$

These relations would hold in a statistical sense and would imply that QSOs with $\mathrm{REW}_{[\mathrm{O\,III}]} \geq 35\ \text{Å}$ typically would have very small BAL region covering factors. They most likely could not be used to predict q_c in an individual QSO. In fact, the possibly heterogeneous nature of the sample suggests that, in the context of an isotropic model, some weak [O III] objects may have covering factors $\ll 0.33$, while others have covering factors $\gg 0.33$.

Unfortunately, based on current observational results it is impossible to distinguish between these two scenarios in a non–model-dependent way. However, one suspects that both scenarios must have relevance—i.e., that viewing angle effects may sometimes be important and that QSOs have a range of intrinsic properties. In any case, it has not been possible in general to observationally rule out or demonstrate possible effects that could modulate $\mathrm{REW}_{[\mathrm{O\,III}]}$, such as viewing angle-dependent continuum emission. For example, the [O III] emission flux could be isotropic, while the continuum emission was not. Another possibility is dusty structures that sometimes obscure part of the narrow-line [O III] emission flux. A better understanding of the implications of various scenarios could be achieved by developing an empirical model that was constrained by multidimensional statistical results on QSO properties similar to the one-dimensional ones specified in equations (1)–(5). In addition, one way to directly investigate this problem in the future would be to make high-resolution imaging observations of low-redshift QSOs. Such observations might be used to derive host galaxy types, explore any connections to ultraluminous IR galaxies, and provide viewing angle constraints.

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