FIRST 0747+2739: A FIRST/2MASS QUASAR WITH AN OVERABUNDANCE OF $\text{C}^\text{iv}$ ABSORPTION SYSTEMS

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ABSTRACT

We present a Keck Observatory/Echelle Spectrograph and Imager spectrum of FIRST 074711.2+273904, a $K = 15.4$ quasar with a redshift of 4.11 that is detected by both the Faint Images of the Radio Sky at Twenty cm (FIRST) survey and the Two Micron All Sky Survey (2MASS). The spectrum contains at least 14 independent $\text{C}^\text{iv}$ absorption systems longward of the Ly$\alpha$ forest. These systems are found over a path length of $\Delta z = 0.984$, constituting one of the highest densities per unit redshift of $\text{C}^\text{iv}$ absorption ever observed. One of the $\text{C}^\text{iv}$ systems is troughlike and resembles a weak broad absorption line (BAL)-type outflow. Two of the $\text{C}^\text{iv}$ systems are “associated” absorption systems with $|v| < 3000$ km s$^{-1}$. Of the 11 remaining systems with $v > 3000$ km s$^{-1}$, eight are either resolved or require multiple discrete systems to fit the line profiles. In addition to $\text{C}^\text{iv}$ absorption, there are two low-ionization Mg $\text{ii}$ absorption systems, along with two damped Ly$\alpha$ systems, at least one of which may be a $\text{C}^\text{iv}$ system. The overdensity of $\text{C}^\text{iv}$ absorption spans a redshift range of $\Delta z \sim 1$. Superclusters along the line of sight are unlikely to cause an overdensity stretching over such a long redshift path; thus, the absorption may be an example of narrow, high-velocity intrinsic absorption that originates from the quasar. We suggest that this quasar is a member of a transitional class of BAL quasars, where we are just barely seeing the spatial, density, or temporal edge of the BAL-producing region (or period); the multiple high-velocity absorption systems may be the remnants (or precursors) of a stronger BAL outflow. If correct, then some simpler absorption-line complexes in other quasars may also be due to outflowing rather than to intervening material.

Subject headings: quasars: absorption lines — quasars: individual (FIRST J074711.2+273904)

1. INTRODUCTION

It is generally agreed that the broad absorption line (BAL) systems seen in the spectra of many quasars are intrinsic to the quasar, arising from high-velocity outflow of gas directly from the accretion disk region (Weymann et al. 1991). Narrow absorption lines in quasar spectra, however, arise from a variety of sources. Narrow absorption lines with small velocities relative to the quasar emission redshift could be caused by galaxies along the line of sight, clouds in the interstellar medium of the host galaxy, or even smaller scale gas flows within a few parsecs of the black hole. On the other hand, most of the narrow absorption systems that have large velocities with respect to the emission redshift of the quasar are thought to be intervening (Sargent, Steidel, & Boksenberg 1988); however, there is increasing evidence that even some fraction of these may be intrinsic. In many BAL quasars, the absorption troughs have considerable structure, suggesting a connection to narrow absorption line systems. We discuss the spectrum of a newly discovered quasar, FIRST J074711.2+273904 (hereafter FIRST 0747+2739), with an overdensity of $\text{C}^\text{iv}$ absorbers in its spectrum. It may be an example of an object whose BAL component has been caught in a transitional state that could be related to orientation, time, or density.

2. DATA

FIRST 0747+2739 was discovered in the early stages of an ongoing project to search for extremely red quasars (Gregg et al. 2002). Candidates are found by matching point sources from the Two Micron All Sky Survey (2MASS; Kleinmann et al. 1994) with the Faint Images of the Radio Sky at Twenty cm (FIRST) radio sources and then further matching to an optical catalog, such as the Automated Plate Machine (APM) catalog (McMahon & Irwin 1992). The object FIRST 0747+2739 has also been discovered independently by Benn et al. (2002). It has $R-K = 2.5$, not particularly red, but it is undetected on the blue Palomar sky survey plate, yielding $B-K \approx 7$. The initial spectrum was obtained using the Kast spectrograph on the Lick Observatory 3 m telescope. A higher signal-to-noise ratio spectrum was obtained at the Keck Observatory using the Low Resolution Imaging Spectrograph (LRIS; Oke et al. 1995), revealing a strikingly rich system of absorption lines redward of Ly$\alpha$.

FIRST 0747+2739 is located at $07^\text{h}47^\text{m}11.208^\text{s} + 27^\circ 39'04.00''$ (J2000.0). There is a 2MASS source within $1''$ with $J$, $H$, and $K$ magnitudes of 16.77, 16.16, and 15.38, respectively. The peak 20 cm flux density as measured by FIRST (Becker, White, & Helfand 1995) is $1.08 \pm 0.14$ mJy; the integrated FIRST flux density is 1.55 mJy.

Motivated by the LRIS spectrum, we obtained a high-dispersion spectrum of FIRST 0747+2739 using the Echelle Spectrograph and Imager (ESI; Epps & Miller 1998) on the Keck II telescope on the night of 2000 April 6. The night was photometric with 0.79 seeing. A 900 s high-resolution spectrum was taken through a 170 slit in the echellelette mode of ESI. In this mode, the spectral range of 3900 to 11000 $\AA$ is covered in 10 spectral orders, with a nearly constant dispersion of 11.4 km s$^{-1}$ pixel$^{-1}$. The signal-to-noise ratio of the spectrum ranges from 20 to 40 per pixel. Wavelength calibrations were performed with observations of a CuAr lamp. The spectro-photometric standard G191-B2B (Massey et al. 1988; Massey & Gronwall 1990) was observed for flux calibration. All ob-
The overdensity of absorption features in the spectrum of FIRST 0747+2739 is immediately apparent in the Keck ESI data (Fig. 1). Also conspicuous are a weak troughlike feature near 7815 Å and two damped Lyα systems. The region longward of Lyα emission is plotted on an expanded scale in the lower panels of Figure 1. We used an automated routine to search this spectral region for absorption lines with significance greater than 10σ. A total of 42 absorption-line systems were identified, 34 being C iv doublets, including a BAL-like C iv trough. The systems are given in Table 1, which lists the system identification code, the redshift, the rest equivalent width of the blue and red components of the C iv doublet (if detected), the “ejection” velocity of the system, and other absorption species belonging to each system. The velocities are with respect to the quasar redshift and are given by \( v = (R^2 - 1)/(R^2 + 1) \), where \( R = (1 + z_{\text{sys}})/(1 + z_{\text{qso}}) \). The individual systems are merged into 18 Poisson systems (14 of which are C iv) by combining absorbers within 1000 km s\(^{-1}\) (Sargent et al. 1988).

### 3.1. Line Densities

How unusual is the abundance of C iv absorbers seen toward FIRST 0747+2739? At high redshift, Steidel (1990) found that (based on 11 quasars) the expected number of C iv absorbers per unit redshift is approximately 1.0 ± 0.5 at \( z \approx 3.25 \) for rest equivalent width larger than 0.15 Å and \( \beta c > 5000 \) km s\(^{-1}\). If we sum the equivalent widths of each of the C iv systems within 150 km s\(^{-1}\) and ignore those three systems with \( \beta c < 5000 \) km s\(^{-1}\), we find seven combined systems with rest equivalent widths larger than 0.15 Å for both lines in the C iv doublet. The path length searched for C iv between Lyα emission and C iv emission is \( \Delta z = 0.984 \). Thus, \( dN/dz \) is 7.11 for this line of sight—an excess of 12 standard deviations from the Steidel (1990) measurement.

For weak C iv lines, Tripp, Lu, & Savage (1996) find \( dN/dz = 7.1 \pm 1.7 \) for \( W_r > 0.03 \) Å and \( 1.5 < z < 2.9 \) (based on four quasars). If we impose constraints on the Tripp et al. (1996) data to match our more conservative 10σ significance limit and combine systems within 200 km s\(^{-1}\), then the density reported by Tripp et al. (1996) is reduced to \( dN/dz = 3.75 \pm 1.25 \). In our Keck ESI spectrum of FIRST 0747+2739, we find, using the same criteria, at least nine distinct high-velocity C iv systems. Over the path length observed, that yields \( dN/dz = 9.1 \pm 3.0 \), which is a 4.3σ excess as compared to Tripp et al. (1996); thus, there is evidence that the overdensity of absorption may extend to weaker systems.

Since Sargent et al. (1988) and Steidel (1990) found that the density of absorption lines decreases with increasing redshift (for strong lines) and since the C iv absorption systems found in FIRST 0747+2739 are at higher redshifts than either the Tripp et al. (1996) or Steidel (1990) samples, our observed density of lines may be even more significant.

What can explain the large overdensity of absorption toward FIRST 0747+2739? All possible explanations can be classified as intervening or as intrinsic. In the intervening case, the ab-
the spectra and tables from Sargent et al. (1988) and Steidel (1990), along with a query of the York et al. (1991) catalog of quasar absorption lines, reveals that such a concentration of C iv absorption over such a long path length is extremely rare. None of the 11 high-redshift quasars from Steidel (1990) has a density of C iv absorption higher than FIRST 0747+2739. Two of the 55 lower redshift quasars from Sargent et al. (1988) do have absorption-line densities higher than FIRST 0747+2739; Q0013-004 (UM 224; z = 2.086) and Q0854+191 (z = 1.896) have six and seven strong (W > 0.15 Å) “Poisson” systems over path lengths of Δz ≈ 0.6, respectively.

Quasars that have relatively high densities of absorption have created much interest in the search for signs of superclustering at high redshift (e.g., Heisler, Hogan, & White 1989; Romani, Filippenko, & Steidel 1991; Foltz et al. 1993; Dinshaw & Impey 1996). However, most of these quasars have absorption systems where the overdensity is very limited in its redshift range, such as CSO 118 (Ganguly, Charlton, & Bond 2001) and the well-studied PKS 0237–233 (Foltz et al. 1993). FIRST 074711.2+273904 is different in the sense that the overdensity of C iv absorption is spread over a large redshift range (Δz ≈ 1)—much too large to be explained by a single supercluster. A search of the NASA/IPAC Extragalactic Database to look for other quasars to test the superclustering hypothesis found no other known quasars within 30 of FIRST 0747+2739, although there are five other radio sources within 10°.

One possible way to reconcile the intervening hypothesis with the absorption-line overdensity in FIRST 0747+2739 is if the quasar is being gravitationally magnified by the intervening material. Such magnification could occur without producing multiple images and might help to explain why a quasar with z > 4 is so bright. The possibility of compound micro-lensing of quasars by their absorption-line systems is not a new concept (Thomas, Webster, & Drinkwater 1995; Vanden Berk et al. 1996). This object, however, is a point source in our Near-Infrared Camera K-band image from the Keck Observatory, obtained in 0.4 seeing.

Finally, it is possible that the apparent overdensity of absorption systems in FIRST 0747+2739 is either just chance coincidence or not actually all that uncommon. The number of high-redshift quasars that are well studied for absorption is still quite small, and additional investigations may yet turn up more cases like FIRST 0747+2739. Such a finding would not necessarily be evidence for either the intrinsic or the intervening hypothesis; however, for now, we conclude that the nature of FIRST 0747+2739 is highly unusual and next to impossible to reconcile with any picture where a significant number of the absorbing systems can be attributed to intervening objects unassociated with the quasar.

3.3. The Intrinsic Hypothesis

Strong circumstantial evidence to support the intrinsic interpretation for the plethora of narrow, high-velocity absorption systems in FIRST 0747+2739 is the presence of similar, almost certainly intrinsic, absorption at low velocities relative to the quasar emission-line frame. System S is typical of intrinsic absorption-line systems seen in other quasars, exhibiting N v absorption and a small blueshift relative to the quasar’s C iv emission redshift. System Q appears to be a weak BAL-like outflow; system P is also broad, but the blue and red components of the troughs are resolved. Finally, system R, with a velocity of only +1600 km s−1, may also be an intrinsic absorption system.
There is ample evidence in the literature for the intrinsic interpretation of high-velocity non-BAL outflows in quasars. Jannuzi et al. (1996) and Hamann et al. (1997a) found weak high-velocity troughlike outflows; Hamann et al. (1997a) showed that the outflows in Q 2345+125 are intrinsic because the absorption profiles varied in ~3.5 months in the quasar rest frame. Richards (2001) and Richards et al. (2001) give statistical evidence that some narrow, high-velocity C IV absorption-line systems may be intrinsic in nature. Finally, Ganguly et al. (2001) discuss an overdensity of C IV absorption in CSO 118.

FIRST 0747+2739 is similar to one of the quasars that comprise the so-called Tololo Pair (e.g., Dinshaw & Impey 1996), namely, Tol 1038−2712, which also has weak BAL-like troughs. This well-studied pair is a favorite for supercluster studies (e.g., Jakobsen et al. 1986), since the two quasars appear to have common absorption-line systems despite the rather large (17.9) separation between the quasars. Other authors (e.g., Cristiani, Danziger, & Shaver 1987; Robertson 1987) still favor the hypothesis that both are BAL quasars, and the absorption is from intrinsic high-velocity outflow. The velocity separation of the lines in the Tololo pair is reminiscent of the double-trough BAL structure found by Korista et al. (1993) for BAL quasars in general, lending credence to the idea that the absorption lines in the Tololo pair are intrinsic. In any case, the similarity of Tol 1038−2712 and FIRST 0747+2739 may help lead to an understanding of the nature of the absorption in both systems.

Q1303+308 provides another interesting comparison; because of its complex absorption structure, it has been classified as a BAL quasar (Foltz et al. 1987); however, the absorption lines are all very narrow and do not meet the traditional BAL criteria set forth largely by the same authors a few years later (Weymann et al. 1991). One must then wonder how we would classify an object with a slightly lower incidence of absorption than Q1303+308. Such an object might simply be classified as a quasar with an overdensity of absorption-line systems much like FIRST 0747+2739.

The fashionable method of determining whether a particular absorption system is intrinsic is either to determine the “coverage fraction” of the quasar or to show that the absorption-line system is variable (Barlow, Hamann, & Sargent 1997; Hamann et al. 1997b). Lacking the data to test for variability, we have analyzed the coverage fractions for each of our systems as a function of velocity. Many of the high-velocity systems do indeed have coverage fractions that are consistent with the intrinsic hypothesis; however, the majority of the systems are resolved into multiple components or blended, which means that the coverage fraction results are not entirely reliable. Thus, on the basis of our covering fraction analysis alone, we are not able to confirm (or exclude) the possibility that the overdensity of absorption lines in this quasar spectrum is due to intrinsic absorption.

Regardless of the lack of conclusive evidence from variability or coverage fractions, the presence of troughlike absorption at moderate velocities and the large redshift span of the overdensity of the C IV absorption points toward an intrinsic origin of at least some of the relatively narrow, high-velocity C IV absorption systems. We suggest that FIRST 0747+2739 is a quasar in transition from (to) a quasi-BAL object to (from) a standard quasar. The lack of strong broad absorption can be explained as being the result of one or more effects. As time goes on, it may be natural for the lines to become narrow as the clouds dissipate down to their small, dense cores; or BAL features might be a superposition of many narrow features, and FIRST 0747+2739 has a relatively low density of them; or perhaps the many narrow absorbers can somehow be attributed to orientation effects.

4. CONCLUSIONS

In summary, we find that overdensity of C IV absorption lines seen along the line of sight to FIRST 0747+2739 is sufficiently high that it is likely that at least some of these systems are high-velocity intrinsic absorption systems. The presence of weak troughlike absorption features suggests that FIRST 0747+2739 may be a transitional BAL quasar that is being observed at a brief phase in its transition to (or from) a standard quasar or is being viewed at a highly specific orientation or that it is a BAL with a very low absorber density. If the absorption is intrinsic, monitoring with high-resolution spectroscopy over the course of ~18 months may reveal variability of the absorbers, a signature of intrinsic absorption. Confirmation (or exclusion) of the intrinsic hypothesis for the unusually large number of high-velocity C IV systems in FIRST 0747+2739 would have interesting consequences for C IV absorption-line studies, particularly high-redshift supercluster-studying studies.

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