1982ApJ...261L...7S

THE ASTROPHYSICAL JOURNAL, **261**:L7–L12, 1982 October 1

SPECTROSCOPY OF THE QSO PAIR Q0028+003/Q0029+003[1]

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Received 1982 March 30; accepted 1982 June 15

ABSTRACT

A prominent narrow absorption-line system has been found in the spectrum of Q0029+003 ($z_{\rm em} = 2.222$) at redshift $z_{\rm abs} = 1.7334$, only 190 km s^{-1} from the emission-line redshift of Q0028+003 ($z_{\rm em} = 1.7317$). It may be due to a galaxy located in a cluster containing Q0028+003; alternatively, it may arise in a halo associated with Q0028+003 and extending at least 520 kpc,[5] the projected separation of the two QSOs at this redshift.

Subject headings: galaxies: clusters of — quasars: absorption lines

I. INTRODUCTION

Direct evidence that narrow metal absorption lines in QSO spectra originate in the extended halos of intervening galaxies has been obtained in three cases (Boksenberg and Sargent 1978; Boksenberg *et al.* 1980; Blades, Hunstead, and Murdoch 1981). In each of these, absorption is seen at the redshift of a galaxy close to the QSO on the sky, but with $z(\text{gal}) \ll z_{\rm em}$ (QSO). Two further cases are known in which QSO absorption lines appear near the redshifts of specific intervening objects (Smith, Burbidge, and Junkkarinen 1977; Burbidge *et al.* 1977).

In all of these cases, the absorption lines are Ca II or Mg II, and their redshifts are relatively small. Young, Sargent, and Boksenberg (1982) have given exhaustive statistical arguments to show that most of the narrow C IV absorption lines found at high redshifts may also arise in the halos of intervening galaxies. The fact that *International Ultraviolet Explorer* (*IUE*) observations of stars in the Magellanic Clouds (Savage and de Boer 1979) and of 3C 273 (Ulrich *et al.* 1980) show relatively strong C IV absorption arising in the outer halo of our own Galaxy provides further support for this hypothesis.

There is also evidence that QSOs are the active nuclei of distant galaxies. Nebulosity, and in some cases extended line emission, have been found surrounding several QSOs (e.g., Kristian 1973; Wampler *et al.* 1975; Stockton 1976; Wyckoff *et al.* 1980*a*, *b*; Wyckoff, Wehinger, and Gehren 1983). Bergeron *et al.* (1982) have mapped [O III] emission from a giant envelope surrounding the QSO MR 2251−178, and their most recent observations (Bergeron, private communication) show that this emission extends out to at least 300 kpc; a clear rotation pattern is seen, centered on the QSO redshift and flattening off at a relative velocity of 180 km s^{-1}.

If most of the metal absorption lines in QSO spectra arise in the extended halos of intervening galaxies, and if QSOs themselves are the nuclei of galaxies, then it should be possible to detect the extended galactic halos associated with distant QSOs in absorption by making spectroscopic observations of still more distant background QSOs which happen to be located nearby on the sky.

To this end we have observed the close pair of QSOs Q0028+003 and Q0029+003: low-dispersion observations to confirm that both are QSOs, and high-dispersion observations to study their absorption spectra. These QSOs were discovered by MacAlpine, Lewis, and Smith (1977) in an objective prism survey; they are both about $V = 18$, and their separation is 62″.

II. OBSERVATIONS AND RESULTS

The two QSOs were observed at low and intermediate dispersion with the European Southern Observatory (ESO) 3.6 m telescope in 1981 September, and at high dispersion with the Anglo-Australian Telescope (AAT) in 1981 October.

The 3.6 m telescope observations were made with the University College London Image Photon Counting System (IPCS) (Boksenberg 1978) on the Boller & Chivens spectrograph used at dispersions of 114 and 59 Å mm^{-1} and with a slit width of 2″; the respective FWHM were 4.7 and 2.5 Å. The image format was 2000 spectral elements by 80 spatial increments each of 1″.60 along the slit. Both QSOs were observed simultaneously whenever possible. The AAT observations were made in a similar way with the IPCS on the Royal Greenwich

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[1] Based on observations made at the European Southern Observatory, Chile and at the Anglo-Australian Observatory, Australia.

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[5] $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = \frac{1}{2}$ are used throughout this paper.

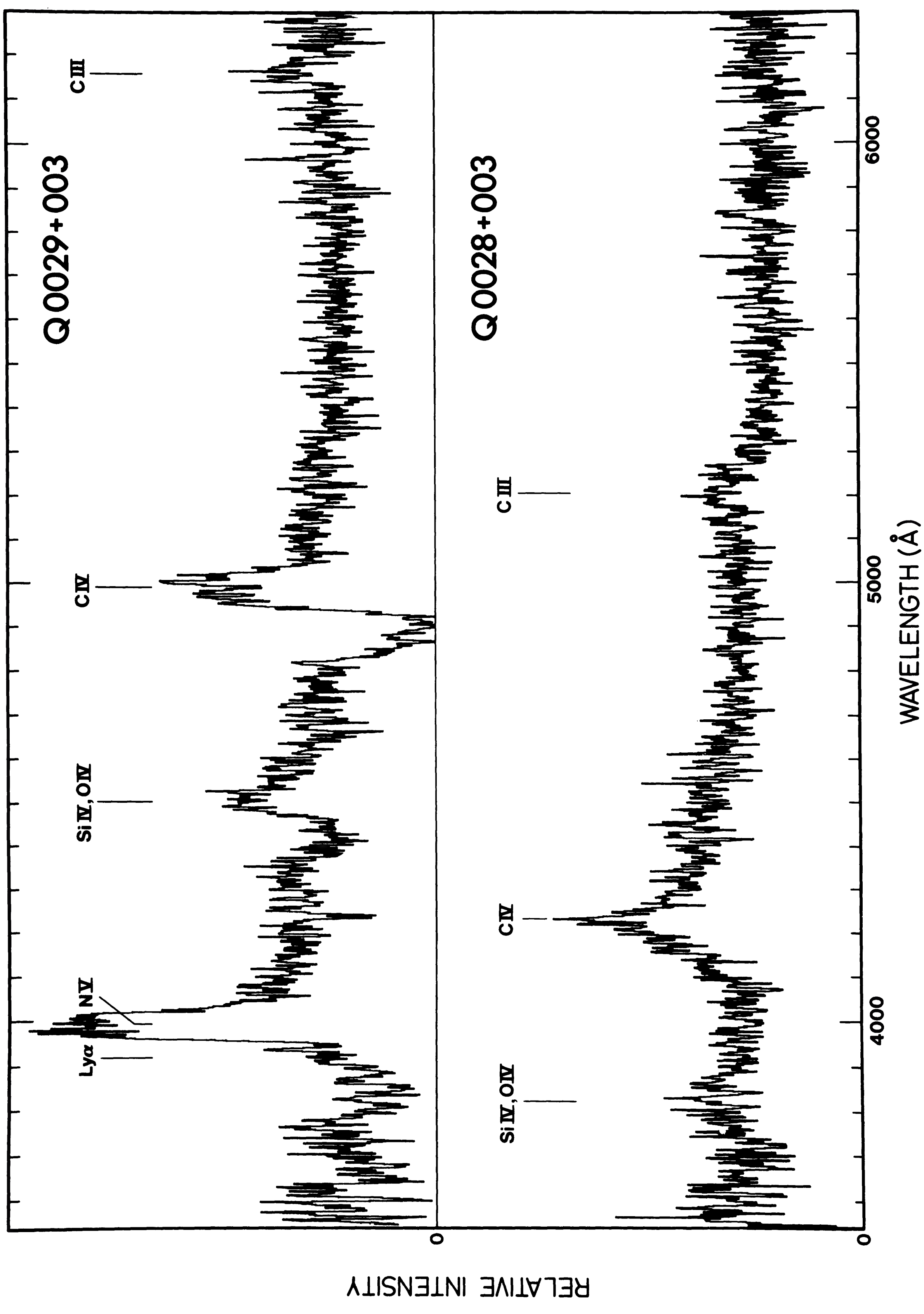

FIG. 1.—Low-dispersion spectra of Q0028+003 and Q0029+003. The resolution is 4.7 Å FWHM, and the wavelengths are vacuum-reduced, heliocentric values. Emission lines are identified.

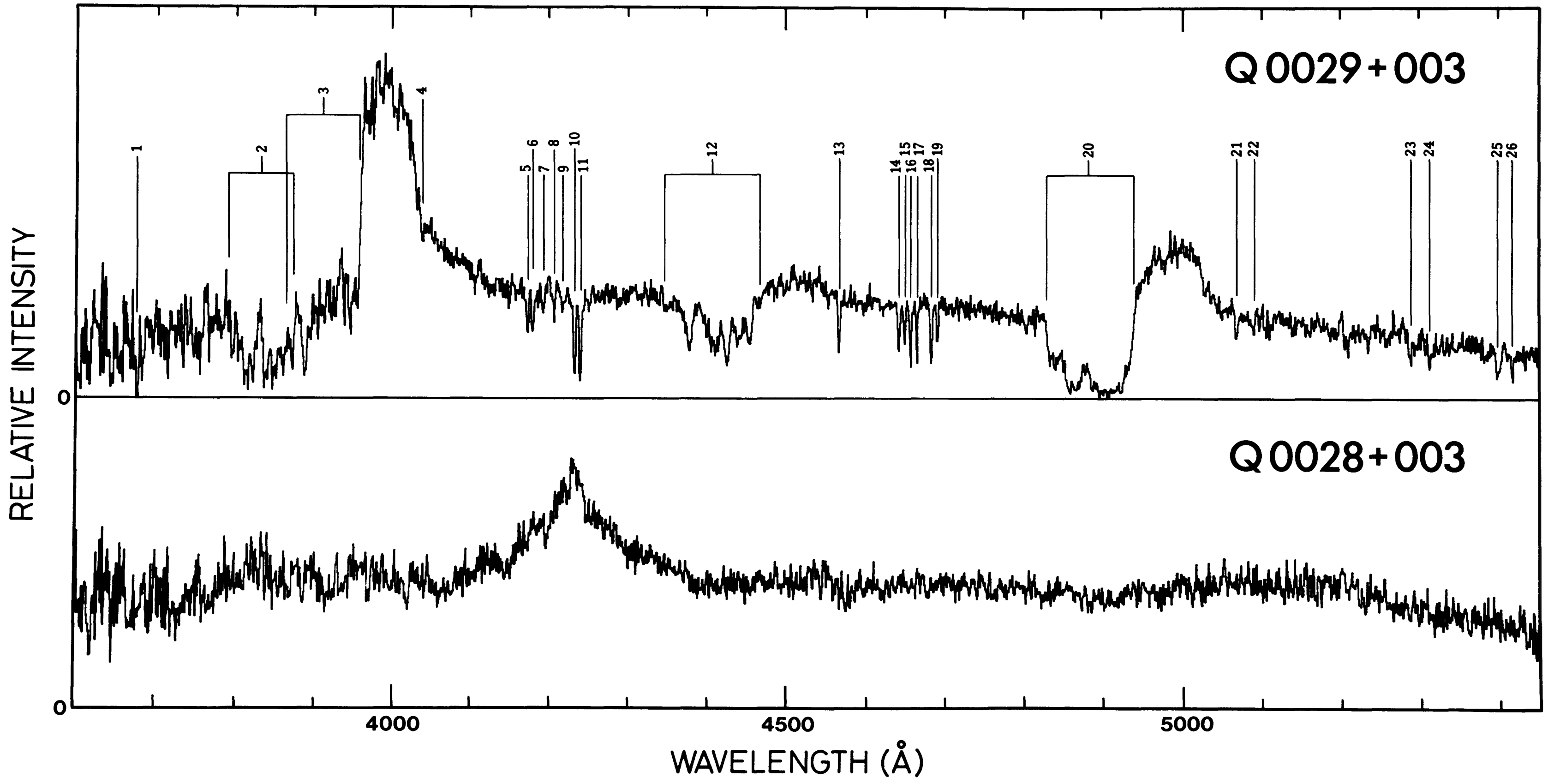

FIG. 2.—Intermediate-dispersion spectra of Q0028+003 and Q0029+003. The resolution is 2.5 Å FWHM, and the wavelengths are vacuum-reduced, heliocentric values. The range 4030–4960 Å contains the weighted average of the intermediate-dispersion and high-dispersion spectra, and the signal-to-noise ratio is correspondingly higher in this region. Absorption lines are identified as in Table 2.

TABLE 1

EMISSION LINES OF Q0028+003 AND Q0029+003

λ (Obs.) (Å)	W_λ (Obs.) (Å)	Identification	$z_{\rm em}$
		Q0028+003	
3821 ± 4	32 ± 6	Si IV + O IV (1399.7[a])	1.730 ± 0.003
4227 ± 2	88 ± 12	C IV (1549.1)	1.729 ± 0.001
4231.5 ± 1[b] ...	...	C IV (1549.1)	1.7317 ± 0.0006[b]
5206 ± 3	41 ± 7	C III (1908.7)	1.728 ± 0.002
			$z_{\rm em}$ = 1.7317 ± 0.0006[b]
		Q0029+003	
3995 ± 1	160 ± 5	N V (1240.1)	2.222 ± 0.001
4508 ± 2	21 ± 3	Si IV + O IV (1399.7[a])	2.221 ± 0.002
4992 ± 1	73 ± 2	C IV (1549.1)	2.223 ± 0.001
6162 ± 3	36 ± 2	C III (1908.7)	2.228 ± 0.003
			$\langle z_{\rm em} \rangle$ = 2.222 ± 0.001

NOTE.—Wavelengths are vacuum, heliocentric values. The quoted errors are 1 standard deviation.

[a] Mean wavelength as determined by Young, Sargent, and Boksenberg 1982.

[b] Measured at the peak of the C IV line, as described in the text.

TABLE 2

ABSORPTION LINES IN THE SPECTRUM OF Q0029+003

No.	λ (Obs.) (Å)	W_λ (Obs.) (Å)	Identification	$z_{\rm abs}$
1......	3676.1 ± 0.3	3.9 ± 0.3	H I (1216)	2.0240 ± 0.0002
2......	3792 - 3873[a]	35 ± 3	H I (1216)	2.119 - 2.186[a]
3......	3864 - 3959[a]	...	N V (1239, 43)	2.119 - 2.186[a]
4......	4038.3 ± 0.3	0.5 ± 0.1	C II (1335)	2.0260 ± 0.0002
5......	4173.1 ± 0.2	1.3 ± 0.2	Si II (1527)	1.7334 ± 0.0001
6......	4179.5 ± 0.2	1.4 ± 0.2	Si IV (1394)	1.9987 ± 0.0001
7......	4192.5 ± 0.3	0.9 ± 0.2	Si IV (1394)	2.0081 ± 0.0002
8......	4206.2 ± 0.3	1.0 ± 0.2	Si IV (1403)	1.9985 ± 0.0002
9......	4216.7 ± 0.3	0.7 ± 0.2	Si IV (1394)	2.0254 ± 0.0002
10......	4232.2 ± 0.2	2.8 ± 0.2	C IV (1548)	1.7336 ± 0.0001
11......	4239.2 ± 0.2	3.0 ± 0.2	C IV (1551)	1.7336 ± 0.0001
12......	4347 - 4469[a]	29 ± 2	Si IV (1394, 1403)	2.119 - 2.186[a]
13......	4566.8 ± 0.2	1.8 ± 0.1	Al II (1671)	1.7333 ± 0.0001
14......	4642.2 ± 0.2	1.6 ± 0.1	C IV (1548)	1.9984 ± 0.0001
15......	4649.5 ± 0.2	1.2 ± 0.1	C IV (1551)	1.9982 ± 0.0001
16......	4657.2 ± 0.2	1.8 ± 0.1	C IV (1548)	2.0081 ± 0.0001
17......	4665.2 ± 0.2	1.3 ± 0.1	C IV (1551)	2.0083 ± 0.0001
18......	4683.4 ± 0.2	2.0 ± 0.1	C IV (1548)	2.0251 ± 0.0001
19......	4691.3 ± 0.2	1.3 ± 0.1	C IV (1551)	2.0251 ± 0.0001
20......	4829 - 4940	79 ± 2	C IV (1548, 51)	2.119 - 2.186
21......	5069.3 ± 0.2	1.2 ± 0.2	Al III (1855)	1.7332 ± 0.0001
22......	5091.0 ± 0.4	0.6 ± 0.2	Al III (1863)	1.7330 ± 0.0002
23......	5289.4 ± 0.4	1.4 ± 0.2	...	...
24......	5314.0 ± 0.3	1.2 ± 0.2	Fe II (2344)	1.2669 ± 0.0001
25......	5400.3 ± 0.4	2.7 ± 0.2	Fe II (2382)	1.2664 ± 0.0002
26......	5418.1 ± 0.2	1.4 ± 0.1	...	...

NOTE.—Wavelengths are vacuum, heliocentric values. The quoted errors are 1 standard deviation.

[a] Derived from the more sharply defined C IV absorption trough.

Observatory spectrograph used at a dispersion of 33 Å mm^{-1} and with a slit width of 1."5; the instrumental FWHM was 1.2 Å. The image format in this case was 2044 spectral elements by 55 spatial increments each of 2."5. Standard flux and wavelength calibration techniques were employed. Further details will be given in a subsequent paper.

The low-dispersion spectra of the two QSOs are shown in Figure 1. The intermediate-dispersion and high-dispersion spectra have been averaged and the result is shown in Figure 2.

Tables 1 and 2 summarize the data on the emission and absorption lines. All wavelengths except one refer to the centroids of the lines; these and the equivalent widths were determined by integrations under the line profiles, and the quoted errors reflect the uncertainty in the baselines chosen. The one important exception is the wavelength given for the peak of the C IV emission line in the spectrum of Q0028+003: it was measured directly after first smoothing with a Gaussian of FWHM 10 Å. The values obtained in this way from the three independent spectra agree within the quoted uncertainty. This method is feasible in this case because the line peak is so sharp and well-defined, and it is important because QSO C IV emission lines are usually asymmetric, the blue wing generally being strongest (Young, Sargent, and Boksenberg 1982). The wavelength of the sharp peak of this line is probably a better measure of the intrinsic redshift, as is the case for nearby active galaxies (Gaskell 1982, and references therein), and it has been used here to obtain the redshift of Q0028+003.

III. DISCUSSION

The spectrum of Q0028+003 is unexceptional, with no obvious absorption features. By contrast, Q0029+003 has both an unusual emission-line spectrum and a rich absorption-line spectrum. It appears at first sight to be one of the few QSOs with little or no Lyα emission (Wright, Peterson, and Jauncey 1979), although in this case its apparent absence may be due to absorption by N V. It is one of the few dozen known "broad absorption-line QSOs" (Weymann, Carswell, and Smith 1981; Young, Sargent, and Boksenberg 1982); as usual, several distinct components are evident, particularly in the broad Si IV absorption trough. Five narrow absorption-line systems have been identified in the spectrum of Q0029+003, at $z_{\rm abs} = 1.2667$, 1.7334, 1.9984, 2.0082, and 2.0251. The latter three are grouped within a range of 2700 km s^{-1} and may originate in galaxies within a single cluster (see Young *et al.*); these and the broad-line features of the spectrum of Q0029+003 will be discussed elsewhere.

The most remarkable feature in the spectrum of Q0029+003 is the narrow absorption-line system at $z_{\rm abs} = 1.7334$, which is only 190 ± 70 km s^{-1} from the emission-line redshift of Q0028+003 ($z_{\rm em} = 1.7317$). It is the most prominent of the five narrow absorption-line systems in the spectrum of Q0029+003 and is relatively isolated from the others in redshift. The fact that it is so close in redshift to Q0028+003, which is only 520 kpc from the line of sight to Q0029+003, suggests that it originates in the immediate vicinity of Q0028+003. If so, this provides the first *direct* evidence that at least some of the *high-redshift* narrow absorption lines in QSO spectra are due to intervening matter located along the line of sight.

The absorption lines in the $z_{\rm abs} = 1.7334$ system appear to be typical in most respects (see Young, Sargent, and Boksenberg 1982, and particularly the very similar $z_{\rm abs} = 1.3650$ system in the spectrum of Q0237−233). The weighted mean deconvolved FWHM of these lines is 170 ± 30 km s^{-1}, while an analysis of the C IV and Al III equivalent widths yields $24 < b < 42$ km s^{-1}, so the presence of substructure in the lines is indicated. The derived column densities (in cm^{-2}) are $\log N\,({\rm C}^{3+}) > 16.3$, $\log N\,({\rm Al}^{++}) = 13.4$, $\log N\,({\rm Al}^{+}) = 13.2$, and $\log N\,({\rm Si}^{+}) = 14.5$. The absorbing region therefore appears to contain normal galaxy material. We defer a detailed analysis of the physical properties of this absorbing region (degree of ionization, radiation field, density, etc.) until we have made high-dispersion observations at the blue end of the spectrum.

These lines may perhaps be due to a galaxy located in the same cluster as Q0028+003. The absence of narrow C IV absorption lines in the spectrum of Q0028+003 itself might be regarded as supporting this view. The fact that the absorption occurs close to Q0028+003 both in velocity and in position would then be a coincidence. Even if this is the case, however, Q0028+003 would still probably dominate the radiation field in the absorbing region.

Alternatively, these absorption lines may be due to material physically associated with Q0028+003. As noted above, Bergeron *et al.* (1982) have mapped [O III] *emission* lines out to 300 kpc from the QSO MR 2251−178; it would therefore not be surprising if gas could be detected in *absorption* out to 520 kpc. This, in addition to the small difference in velocity (190 km s^{-1}), suggests that the absorption lines might originate in the extended halo of Q0028+003 itself. The absence of obvious narrow C IV absorption lines in the spectrum of Q0028+003 may be explained if the "halo" is an inclined disk. If the absorption lines do indeed arise in quiescent halo material of the underlying galaxy, with a well-defined rotation curve (as in the case of MR 2251−178), the rotation velocity of 190 km s^{-1} at a radius of 520 kpc would imply a total mass of $4 \times 10^{12}/\sin^2 i\ M_\odot$ within that radius, where i is the inclination angle.

We thank the technical support group at La Silla for their help in installing the UCL traveling IPCS on the

3.6 m telescope, and John Fordham and Keith Shortridge for setting up, maintaining, and operating the IPCS during the observing run. The IPCS was developed with the aid of grants from the UK Science and Engineering Research Council. P. A. S. is grateful to Joe Wampler for helpful discussions. We thank the Australian Time Assignment Committee of the AAT for the allocation of observing time for this project.

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