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DIGICON SPECTROPHOTOMETRY OF THE QUASI-STELLAR OBJECT PHL 957

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ABSTRACT

Measurements of the spectral region centered on the broad Lα absorption in the QSO PHL 957 have been made with the UCSD Digicon (digital image tube) at the Cassegrain focus of the Lick 120-inch (305-cm) telescope, and photographic spectra have also been obtained over a wider spectral range. The broad absorption is very deep, with an intensity less than 2 percent of the continuum over the central 30 Å. The profile of the broad absorption and the relationship between this feature and the other multiple-redshift systems found in PHL 957 by Lowrance *et al.* is discussed. Absorptions arising from excited fine-structure states of some ions may be present. If the central part of the Lα feature arises in the same gas as produces the C II line at 4415 Å, the C/H ratio may be $\sim 10^2$–10^3 lower than normal. Alternatively, most of the Lα broad absorption may consist of multiple Lα lines arising in a gas with a velocity range exceeding 1000 km s^{-1} in which case C/H may be normal. Probably all the absorptions arise in gas associated with the QSO.

I. INTRODUCTION

In this paper we describe recent observations of PHL 957 made with the Digicon digital image tube at the Cassegrain focus of the Lick 120-inch (305-cm) telescope. The spectrum of this QSO, which has been discussed by Lowrance *et al.* (1972), hereafter referred to as LMZOS, and by Morton and Morton (1972), is remarkable for its large number of absorption lines. The most striking and perhaps most interesting of these is the extremely broad absorption trough centered at approximately $\lambda =$ 4020 Å and identified by LMZOS as Lα at a redshift of $z_1 = 2.3090$.[1] This feature has therefore been studied at a nominal resolution of $\sim$8.0 Å, using the prototype 38-element Digicon.

The results, together with relevant data derived from conventional and image-tube spectrograms, are presented here. It is shown that (i) the mean flux in a 30 Å band at the center of the 4020 Å feature is less than 2 percent of the continuum; (ii) only part of the 4020 Å feature can arise in gas with a very small velocity dispersion as derived by LMZOS from the width of the C II feature at 4415 Å in the same redshift system; (iii) the wings of the feature at 4020 Å may be accounted for in terms of lines arising from other ions in the redshift systems C and D of LMZOS ($\langle z_1 \rangle = 2.2056$ and 2.2250, respectively), although this would involve lines arising from excited fine-structure levels (alternatively, these wings may be ascribed to further Lα absorption at somewhat different redshifts); (iv) the central part of the 4020 Å Lα feature is con-

[1] In what follows, we shall use $z_1 = (\lambda_{obs}/\lambda_{lab})$ rather than the values of z derived by LMZOS by correcting observed wavelengths to vacuum values.

sistent with the absorption expected if the light from PHL 957 passed through a face-on spiral galaxy at $z_1 = 2.3090$ (this interpretation seems rather implausible to us, however, in view of the probable existence of C II λ1335.68 arising from the 0.01-eV fine-structure level in this redshift system, and the presence of so many other absorption-line systems [even at higher blueshift relative to the emission lines] that cannot be ascribed to such chance interventions); and (v) the possibility that absorption systems with high relative blueshift in other QSOs (for example, in PHL 938, $z_{\rm abs} = 0.613$, $z_{\rm em} = 1.955$) could be due to such intervening matter, also seems less likely in view of the present results.

The possibility of line-locking of absorption systems has been discussed for other QSOs in connection with a model for producing multiple redshifts in absorption lines by means of gas outflow driven by radiation pressure. In § IV we shall briefly discuss this possibility for PHL 957.

II. OBSERVING EQUIPMENT

A prototype Digicon image tube with a cesium antimonide photocathode (~5.6 percent quantum efficiency at 4000 Å) and a 38-element silicon diode array at the electron focal plane was designed at the University of California, San Diego, and constructed by the Electron Vision Corporation. Details of the properties of this system and the associated electronics have been published elsewhere (Beaver and McIlwain 1971). Here we need only note that the sensitive area of each diode measures 89 $\mu \times 89\ \mu$, over which the response is very uniform, and that the diodes are arranged in the form of a linear array with a pitch of 101 μ.

The tube was further tested at the coudé focus of the Lick 120-inch (305-cm) telescope using, in the first instance, light fed from the 24-inch (61-cm) auxiliary telescope. The results, mainly line profiles in brighter stars (to be published elsewhere), were greatly enhanced by substepping the diode array one-quarter element by using magnetic deflecting coils on the side of the image tube. Since no major difficulties were encountered with the system, it was then transferred to the Cassegrain focus of the 120-inch telescope.

The construction of the prototype Digicon includes a rather thick (4.75 mm) lime glass-quartz face plate on the inside of which is the photocathode. The thickness of this face plate caused some problems in matching the system to the available spectrograph, which had been built at the University of California, Los Angeles, for another purpose. The existing F/1.0 Schmidt camera was replaced by an F/3.0 Doublet Quartz lens imaging system[2] which gives 25-μ resolution over the 4 mm of spectrum observable at any one time with the present tube. Because the focal plane is curved, camera focus and Digicon tilt adjustments were necessary whenever changes were made in the observed spectral range.

Digicon observations were carried out on 1971 October 25 at the Lick Observatory. Field acquisition and guiding at the Cassegrain focus were carried out by means of the TV remote-control system designed and built at the University of California, Santa Cruz, by Dr. E. J. Wampler and Dr. Lloyd Robinson. A dispersion of 76.6 Å mm^{-1} was used, giving a nominal resolution of ~8.0 Å and a range of ~300 Å. The tube dark current was measured to be less than 1×10^{-3} counts per second per diode. In order to optimize resolution, integrations were repeatedly made with the spectrum

[2] The system gave a reduction of ~5.5 between slit and detector so that each diode corresponded approximately to 500 μ or 2 arc sec at the slit. In this respect the system was not optimum since the detection rate at maximum (~90 μ) resolution decreased quadratically with the size of the seeing disk when this exceeded ~2 arc sec, which it almost invariably did. These difficulties are clearly not intrinsic to the Digicon system and could be solved by using a faster camera and/or increasing the diode dimension perpendicular to the direction of dispersion.

TABLE 1

SPECTROGRAPHIC OBSERVATIONS OF PHL 957 ADDITIONAL TO DIGICON OBSERVATIONS

Plate No.*	λ (Å)	Dispersion (Å mm^{-1})	Exposure (min)
ES 2017......	3200–5000	370	90
EI 137.......	4000–7200	450	30
ES 2022......	3550–4550	190	160
ES 2111......	3550–4550	190	120
SI 449	3500–5400	90	90

* ES is Lick photographic prime focus spectrograph, EI is Lick Carnegie image-tube prime focus spectrograph, SI is Steward RCA image-tube Cassegrain spectrograph.

successively in one of four positions with respect to the diode array, each separated by one-quarter diode size along the direction of dispersion. The sky contribution was measured in the same fashion with the telescope displaced from the object, although in principle a magnetic deflection could also have been used for this purpose. Measurements of star and sky were made repeatedly throughout the observation.

In good seeing conditions the photon detection rate was 0.4 counts per second per diode which, for purposes of comparison with other systems, corresponds to 0.2 counts s^{-1} Å^{-1} at $m_v = 15$. This is consistent with a Digicon detective quantum efficiency of $\sim$5 percent at 4000 Å, the value determined in the laboratory. It should be noted that a new replacement tube exhibits 20 percent quantum efficiency at 4000 Å and that further gains could be achieved with a bi-alkali cathode. Only a relative calibration of the respective diode/cathode combinations was made; absolute photometry was not attempted.

The conventional spectroscopic data used here were obtained with the prime-focus photographic spectrograph at Lick Observatory and with the Cassegrain image-tube spectrograph at the Steward Observatory. Details of the plate material are summarized in table 1.

III. RESULTS

The Digicon results are presented in figures 1–3, where each point represents integrations at a quarter step. Figures 1 and 2 show the raw data for PHL 957 and for the sky, respectively. The data were accumulated over a total time of approximately 2 hours divided equally between object and sky and among the four positions of each diode.

In figure 3 we show the result after sky subtraction and normalization of relative diode response. In order to reduce statistical noise, the data have been filtered according to the running mean

$$Y_i = \tfrac{1}{4}(X_{i-1} + 2X_i + X_{i+1})$$

where X_i denotes the count at quarter step positions. The Fourier transform of this convolution is

$$\tilde{Y}_i = \cos^2(\pi f_i) \times \tilde{X}_i ,$$

where $f_i = (i - 1)/152$, and $\tilde{X}_i$ is the transform of X_i data. The filtering has a small effect on the modulation transfer function of the system, yet it removed a considerable

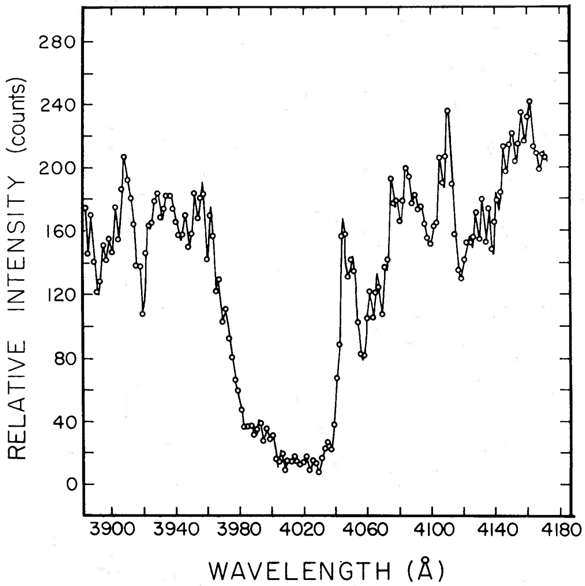

FIG. 1

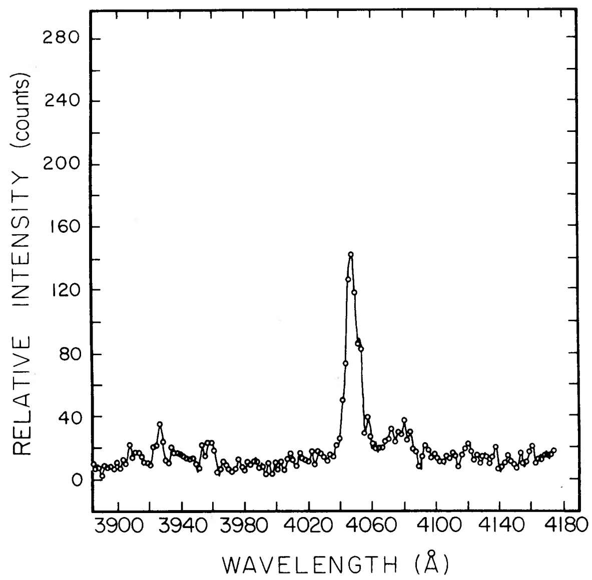

FIG. 2

FIG. 1.—Digicon measurements of spectrum of PHL 957, before sky subtraction
FIG. 2.—Digicon record of sky spectrum; strong line at 4046 Å is Hg

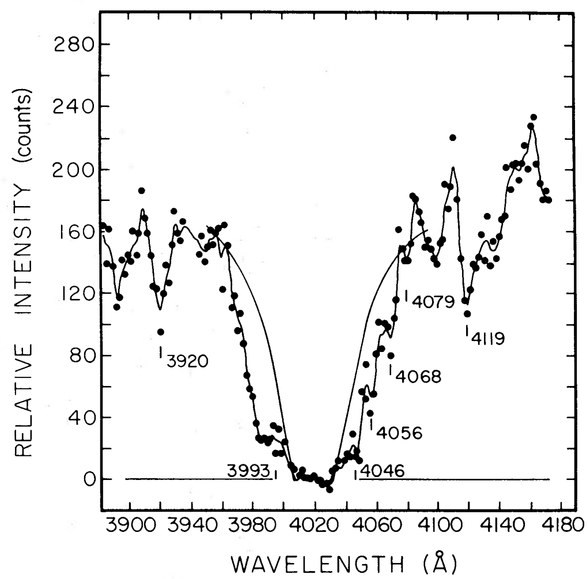

FIG. 3.—Digicon measurements of PHL 957 after sky subtraction. Note the good subtraction of Hg λ4046, and the extremely low intensity in the central 30 Å of the strong Lα absorption. Also shown are the optimum interpolated spectrum (see text) and the theoretical radiation damping profile for a neutral hydrogen column density of $N \sim 2 \times 10^{21}$ cm^{-2}.

amount of the Gaussian white noise. If in the Fourier space the data are truncated so that

$$\tilde{Y}_i^t = \tilde{Y}_i\,, \qquad 0 \le f_i < 1\,,$$

$$\tilde{Y}_i^t = 0\,, \qquad f_i < 0\,, f_i \ge 1\,,$$

the inverse Fourier transform of $\tilde{Y}_i^t$ is the continuous function of figure 3 and represents optimum interpolation according to sampling theory. For comparison purposes we present the intensity tracing (fig. 4) of Lick spectrogram ES 2022 which is reproduced in figure 5 (plate 1). The effective resolution of the Digicon with quarter stepping appears to be rather better than the nominal value of 8 Å. We also draw attention to the accuracy with which we were able to subtract the Hg λ4046 nightsky feature. The statistical uncertainty in the region of this line is, however, inevitably increased, and we shall therefore attach more significance to results for the violet than for the red edge of the absorption feature.

It is quite clear that at the center of the trough there is a region with a width of approximately 30 Å over which no net radiation has been detected from PHL 957. The results look rather like the interstellar Lα absorption features found in the ultraviolet spectra of early-type stars (Savage and Jenkins 1972) and raise the possibility that absorption in an intergalactic cloud or intervening galaxy may be responsible. LMZOS have shown that C II λ1334.5 in the same redshift system ($\lambda_{\rm obs}$ = 4415 Å) has a Doppler width of less than 30 km s^{-1}, and it therefore is of interest to inquire how much of the λ4020 Lα feature can arise from a gas with such a low velocity dispersion. It is, of course, immediately clear from the structure in the short-wavelength wing that the whole feature could not arise in this way.

Our results enable us to set an upper limit (3 σ) of ~2 percent of the continuum on the average flux in a ~30 Å band centered at 4022 Å (the precise wavelength of Lα at a mean z_1 = 2.3090).

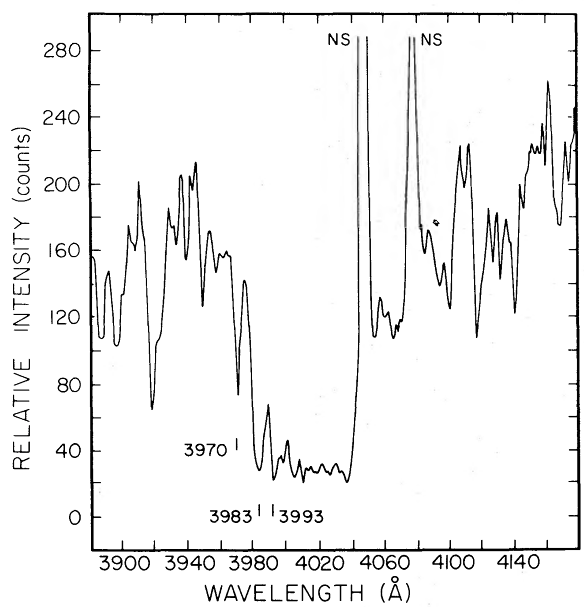

FIG. 4.—Microphotometer tracing of Lick photographic plate ES 2022

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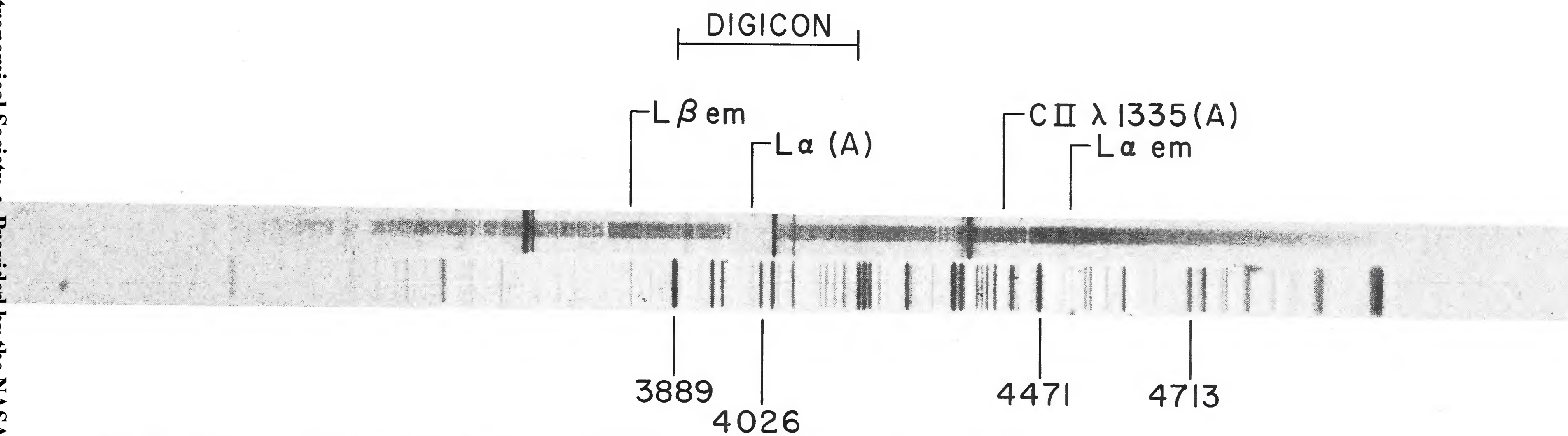

FIG. 5.—Spectrogram ES 2022 of the QSO PHL 957 obtained at the prime focus of the Lick 120-inch telescope at a reciprocal dispersion of 204 Å mm^{-1}.

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IV. DISCUSSION

If we assume that the central trough of the λ4020 feature is indeed due to Lα in the same gas that produces the C II λ1334.5 line, we have

$$1/30 \int_{-15}^{+15} \exp(-\tau_\lambda) d\lambda \lesssim 0.02 .$$

Since in the wings of a line of this width and central depth the Doppler broadening may (to a sufficient approximation) be neglected, we may write

$$\tau_\lambda = \frac{2.9 \times 10^{-26} N}{(\lambda_c/\lambda - 1)^2} ,$$

where N denotes the number of hydrogen atoms in the ground state per cm^2 column in the line of sight and λ_c is the central wavelength of the absorption feature. Using the observed upper limits, we find $N \gtrsim 1.3 \times 10^{21}$ cm^{-2}, and the corresponding profile for $\Delta\lambda = |\lambda - \lambda_c| \gtrsim 15$ Å is shown in figure 3 on the basis of an approximate mean continuum level of 180 counts. No inconsistency is apparent, although only part of the λ4020 profile can be accounted for in this manner.

An alternative and perhaps a preferable procedure is to use one or two diodes at $\Delta\lambda \sim 15$ Å from the line center to obtain estimates of τ_λ at that wavelength. The upper limit on the flux for the reduced number of points is, however, rather higher. The derived value of $N \gtrsim 1.0 \times 10^{21}$ cm^{-2}. The lower limits on N depend on how much of the *central* part of the 4020 Å feature is ascribed to Lα, rather than to still more lines in other systems. This uncertainty may cause a reduction in $\Delta\lambda$ upon which N depends as $N \propto (\Delta\lambda)^2$. The dependence of N on ascribed continuum level is only logarithmic, so that little significant error should be introduced by uncertainties in this quantity. Due to the exponential sensitivity of the profile to N, it is very unlikely that N could much exceed the values derived here. This value of the hydrogen column density is of interest since it is comparable to the number of neutral hydrogen atoms in a line of sight perpendicular to the plane of a typical spiral galaxy and raises the possibility that the absorption may be produced by such a galaxy lying between the QSO and the observer.

As a further check on consistency we have therefore evaluated the expected Lβ profile under the same assumptions. We find an equivalent width W(Lβ) $\sim$ 15 Å, with a core of essentially zero flux (< 1 percent) extending $\sim$2.5 Å on either side of the predicted wavelength (3394 Å) of this feature. These values are not inconsistent with the present observational material, which is unfortunately of rather low quality due to poorer focus and decreasing grating response at this wavelength. Clearly, Digicon observations of this feature are also required. Our impression is that, if anything, the observed Lβ may be somewhat stronger than that predicted.

The remaining structure in the wings of the λ4020 feature is clearly of importance in this context. Wavelengths of possible absorption lines are given in table 2. The features at λ3970 and λ3983 can be attributed to N V $\lambda\lambda$1238.8, 1242.8 at $z_1 = 2.2056$ (System C as defined by LMZOS), although, as they have pointed out, the second line appears rather strong. It could, however, be blended with Si II λ1260.42 at a redshift $z_1 = 2.1573$ (System J), which might account for the inaccurate fit of the Si II line in System J. The Si II λ1264.8 line arising from the 0.04-eV fine-structure level could then be identified with a possible feature at 3993 Å, present on our spectrograms and in the Digicon results, although such an identification would cause serious difficulty if the cloud were not near the QSO (Bahcall and Feldman 1970). An alternative identification would be with Si III λ1206.5 in System A ($z_1 = 2.3090$), although this would require a somewhat higher degree of ionization than found so far. In any event, it

TABLE 2

DISCRETE ABSORPTION FEATURES IN THE WINGS OF Lα AND SUGGESTED IDENTIFICATIONS

WAVELENGTH (Å)		
Present	LMZOS	POSSIBLE IDENTIFICATION
3969.8	3970.6	N v λ1238.8 (C; 3971.1)
3982.3	3983.7	N v λ1242.8 (C; 3983.9); Si II λ1260.4 (J; 3979.5)
3992.8	...	Si II λ1264.8 (J; 3993.4); Si III λ1206.5 (A; 3992.3)
4046:*	...	Si II λ1260.4 (C; 4040.3)
4056*	4053.6	Si II λ1264.8 (C; 4054.4)
4068*	4066.0	Si II λ1260.4 (D; 4064.7)
4079*	...	Si II λ1264.8 (D; 4079.0)

NOTE.—A colon indicates very uncertain due to nightsky subtraction.
* Digicon measurements.

appears possible to account for much of the additional structure in the blueward wing of the λ4020 feature in terms of reasonable line identifications. It is not clear, of course, that these would account for all the observed structure apart from Lα; nor can it be excluded that part or all of this structure is due to further Lα features (cf. Lynds 1971).

Our measurements of the redward wing of the Lα absorption feature at 4020 Å are rather less accurate because of the need to subtract the Hg λ4046 nightsky line. Nonetheless there appears to be a suggestion of a number of discrete absorption features at wavelengths given approximately (±3 Å) in table 2. Two of these have also been noted by LMZOS, which encourages us to believe that the others may likewise be real. Possible identifications for these features in redshift systems C and D are also noted in table 2. The agreement seems to be sufficiently good to indicate that these lines, which in some cases arise from excited fine-structure levels, are indeed present. If so, this would establish that the material producing these lines is close to the QSO. An alternative explanation of these lines and of any additional absorption in the redward wing could again be given in terms of Lα at redshifts this time somewhat larger than the bulk of the gas giving rise to System A.

If we accept that the wings of the Lα feature at 4020 Å are produced by lines of other elements in different redshift systems, there appears to be no reason to doubt that the central part of the feature could arise in the same gas as produces the C II line at 4415 Å. In view of the uniqueness of the Lα structure in this QSO and its similarity to interstellar absorption features observed in OB stars (Savage and Jenkins 1972), the question thus arises as to whether the lines of System A—but not of course, of the other systems—could arise in an intervening galaxy. We feel that this is rather implausible, however, because of the considerable number of possible absorption line systems with greater blueshifts relative to the redshift given by the emission lines and the remarkable accumulation of lines of other intrinsic systems in the wings of Lα. This could be attributed only to chance if System A arises in an intervening galaxy but could arise in a natural way from "line-locking" in an object undergoing mass loss driven by radiation pressure (Burbidge 1968; Mushotzsky, Solomon, and Strittmatter 1972), the lines then being intrinsic to the object.

The most serious objection to the intervening-galaxy interpretation is the probable presence in the TV spectrum of LMZOS of C II λ1335.68 arising from an excited fine-structure level of 0.01 eV. The feature in question is their weak line no. 123 at 4418.94 Å which, if we adopt $\langle z_1 \rangle = 2.3090$, is displaced by only $\Delta\lambda = -0.25$ Å from its expected position, compared to $\Delta\lambda = -0.29$ Å for the much stronger zero-volt C II λ1334.23

line (no. 122). If this is confirmed, it would rule out the intervening-cloud hypothesis. It therefore seems more likely that the material producing the absorption of System A is intrinsic to PHL 957.

In either event, it may be shown that, if the central part of the Lα absorption at 4020 Å and the C II line at 4415 Å are produced in the same gas, carbon must be seriously underabundant compared with the solar-neighborhood abundance. Morton and Morton (1972) have deduced a column density $N_{\rm C\,II} \sim 10^{15}$ from the line at 4415 Å. With the exception of the "doubtful" identification of N V λ1238.81 in this system the remaining lines are, according to LMZOS, all of neutral or once-ionized elements. No C I lines are, however, found although λ1277 and λ1656 should be readily detectable if comparable quantities of neutral C were present. It therefore seems reasonable to assume that most of the C is in the form[3] C^+ from which an abundance ratio $C/H \leqslant 5 \times 10^{-6}$ would follow. Either carbon is very underabundant[4] in this gas cloud or we must abandon our assumption that the entire central "zero" flux portion ($\pm$15 Å) of the Lα line at 4020 Å arises in the same gas cloud as the C II line at 4415 Å.

If we accept the Lα interpretation of the wings of the λ4020 line, then the difference in velocity dispersion requires explanation. We consider it extremely unlikely that separation of elements and different turbulent velocities are responsible for this difference, as was suggested by Morton and Morton (1972). A more plausible explanation may run as follows. Material with $N_{\rm C\,II} \approx 10^{15}\ \rm cm^{-2}$ with low velocity dispersion ($\leqslant 30\ \rm km\ s^{-1}$) gives rise to the λ4415 line. The associated hydrogen, for which $N_{\rm H} \sim 3 \times 10^{18}\ \rm cm^{-2}$ if the C/H ratio is normal but for which $N_{\rm H} \leqslant 2 \times 10^{21}\ \rm cm^{-2}$ in any case, gives rise to a central absorption feature. In addition, further material with a relative motion of up to $\sim 3000\ \rm km\ s^{-1}$ gives rise to the wings of the λ4020 feature. The minimum column density of material at each velocity is then of order 10^{15}–$10^{16}\ \rm cm^{-2}$ and would not at this level give rise to any C II absorption if the C/H ratio were normal or less than normal. The profile of Lβ would be made up in a similar way. No inconsistency with available data on Lβ can be demonstrated, but an accurate Digicon profile of the Lβ feature could in principle decide whether hydrogen gas clouds at this large range of velocities are present. Such a spread in velocities would provide evidence in favor of the hypothesis that gas is flowing outward from the QSO under the influence of radiation pressure at velocities partially controlled by gradients in radiation pressure with wavelength—for example, in the wings of resonance lines or near photoionization edges. Provided radiative acceleration and gravity are comparable, "line-locking" would occur; that is, certain relative velocities would be preferred as the Doppler-shifted wavelength of the driving resonance line in one gas cloud (or layer) approaches that of a resonance line in gas nearer the central source of continuum radiation (cf. Mushotzsky *et al.* 1972). Accurate profiles of both Lα and Lβ might give constraints upon the allowed distribution of velocities in the outward flow.

It is, of course, extremely unlikely that an intervening galaxy or cloud could contain material with the required velocity dispersion (1–$3 \times 10^3\ \rm km\ s^{-1}$). Other arguments, mainly of a statistical kind, have been given previously against the intergalactic-cloud model; in particular we cite the arguments of Roeder and Verreault (1969) against finding so many different absorption line redshifts in, for example, PKS 0237−23. Our purpose here was to examine an individual case in which more detailed informa-

[3] The line C III λ977 should be detectable at 3224 Å if C^{++} is present in substantial quantities. Our spectrograms show no evidence for this line, nor is it listed by LMZOS, but no definite conclusion can be drawn from its absence because the wavelength lies close to the lower wavelength limit of both sets of observations.

[4] The results of Morton and Morton do not conclusively exclude the possibility that the C II λ1335 line could have a radiation-damping profile, in which case $N_{\rm C\,II}$ could be as high as $10^{18}\ \rm cm^{-2}$ and the carbon abundance therefore normal.

tion was available. Indeed the redshift systems in PHL 957 may contain still more evidence against the intergalactic-cloud hypothesis in that there appear to be a large number of observed wavelength coincidences between different lines in the various redshift systems. For example, we note that Lβ in the A System coincides approximately with the Lyman limit in the emission-line system; also, as noted above, N v λ1242 and Si II λ1260 in systems C ($z_1 = 2.2056$) and J ($z_1 = 2.1573$), respectively, appear at the short-wavelength edge of the Lα absorption in System A. A glance at table 5 of LMZOS shows how often such coincidences occur. Although it is difficult to estimate whether a significant excess of wavelength coincidences is present, such occurrences clearly complicate the task of assessing the reality of absorption-line systems on the basis of wavelength measures and relative line strengths. If an excess of such "blends" could be demonstrated, it would confirm that the absorption lines are intrinsic to the QSOs. As noted above, such approximate wavelength coincidences could occur naturally in an object undergoing mass loss driven by radiation pressure.

V. CONCLUSIONS

Results of Digicon and conventional spectrographic observations of PHL 957 have been presented. The Digicon system functioned satisfactorily in all respects and appears to have considerable astronomical potential as a highly efficient, stable photon-counting device. The observations of PHL 957 enabled us to conclude the following.

1. The flux in a 30 Å interval at the center of the 4020 Å Lα absorption feature is less than 2×10^{-2} of the continuum level.
2. The wings of this broad absorption cannot be due to Lα absorption in gas with the same velocity dispersion as produces the C II feature at 4415 Å in the same redshift system (A).
3. If the central part of the broad absorption is produced in the same cloud as the C II line, carbon must be underabundant by a factor 10^2–10^3 compared to the Sun.
4. A number of hitherto unidentified lines could be associated with transitions occurring from excited fine-structure levels in redshift systems suggested by LMZOS. In particular, the 0.01-eV C II λ1335.68 appears to be present in System A.
5. The absorption-line systems, including System A, probably arise in material associated with the QSO.
6. In view of the high relative blueshifts of some of these intrinsic absorption systems, there appears to be no reason to ascribe lines in other QSOs which are highly blueshifted relative to the emission lines, for example in PHL 938, to clouds or galaxies at smaller cosmological redshift.

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REFERENCES

Bahcall, J. N., and Feldman, U. 1970, *Ap. J.*, **161**, 389.
Beaver, E. A., and McIlwain, C. E. 1971, *Rev. Sci. Instr.*, **42**, 1321.
Burbidge, E. M. 1968, private communication.
Lowrance, J. L., Morton, D. C., Zucchino, P., Oke, J. B., and Schmidt, M. 1972, *Ap. J.*, **171**, 233 (LMZOS).
Lynds, R. 1971, *Ap. J.* (*Letters*), **164**, L73.
Morton, D. C., and Morton, W. 1972, *Ap. J.*, in press.
Mushotzky, R., Solomon, P., and Strittmatter, P. 1972, *Ap. J.*, **174**, 7.
Roeder, R. C., and Verreault, R. T. 1969, *Ap. J.*, **155**, 1047.
Savage, B. D., and Jenkins, E. B. 1972, *Ap. J.*, **172**, 491.