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DETECTION OF 21 CENTIMETER ABSORPTION AT $Z \approx 1.94$ IN THE QSO PKS 1157+014

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ABSTRACT

We report the detection of 21 cm absorption by neutral hydrogen in front of PKS 1157+014, a QSO with emission redshift $z_{em} = 1.978 \pm 0.008$. The absorption line arises at 482.537 ± 0.002 MHz, corresponding to a redshift $z_{abs} = 1.94362 \pm 0.00001$ that is identical, within observational errors, to the previously detected optical redshift of absorption system *d*. The coincidence between radio and optical redshifts reinforces the case for uniformity of physical laws throughout most of spacetime. The presence of several other absorption systems, along with this one, spanning a range in z_{abs} corresponding to velocities from $+1000$ to -8500 km s^{-1} suggests that this system, along with the others, is ejected from QSO. However, the determination of the spin temperature T_s from a comparison of Lyα and 21 cm absorption spectra argues against this interpretation. Our upper limit of $T_s < 470$ K places system *d* farther than 10 kpc from the QSO to avoid excitation effects of the 21 cm continuum. At this distance the absorption system requires 100 times more radiative momentum than the QSO can offer. Instead, we suggest that system *d* is part of an H I disk of a galaxy gravitationally bound to a cluster containing the QSO.

Subject headings: cosmology — galaxies: redshifts — quasars— radio sources: 21 cm radiation

I. INTRODUCTION

The radio source PKS 1157+014 has been identified with a QSO that has an emission redshift $z_{em} = 1.978 \pm 0.008$ and seven absorption redshifts ranging from $z_{abs} = 1.9881$ to $z_{abs} = 1.7203$ (Wright *et al.* 1979). The absorption spectrum shows broad features due to Lyα, N V, and C IV, where the N V and C IV features are due to the superposition of several highly ionized and closely spaced absorption systems. However, Lyα, the broadest feature observed, is centered near $z_{abs} = 1.9438$, a redshift system that exhibits weak C IV, stronger Si IV, no N V, and narrow C II, Si II, Fe II, Al II, and O I absorption lines. Redshift systems with such a low level of ionization and very strong Lyα absorption are rarely found among absorbers with redshifts this close to z_{em}, since the latter tend to be highly ionized (Weymann 1980). Rather, the large ratio of Lyα to heavy-element equivalent widths suggests that the $z_{abs} = 1.9438$ absorber (system *d* of Wright *et al.* 1979) in PKS 1157+014 is an extremely opaque H I region and therefore is a promising candidate for a search for 21 cm absorption (cf. Wolfe 1980).

Motivation for this search came from the following considerations: First, the detection of Lyα and 21 cm absorption in the same material allows a determination of the hyperfine spin temperature T_s, a variable sensitive to local excitation conditions. Second, system *d* has a velocity of less than 10^4 km s^{-1} with respect to the emission redshift, which suggests two possible origins: Either the absorber originates in the QSO or it belongs to a foreground galaxy in a system gravitationally bound with the QSO (cf. Weymann *et al.* 1979). This is in sharp contrast to the much larger redshift differences that separate absorber from QSO in the other four absorption systems, with observed redshifted 21 cm lines. Indeed, independent evidence suggests that at least two of these absorbers are intervening galaxies (Wolfe 1980).

Finally, the detection of 21 cm absorption in PKS 1157+014 enables an accurate comparison to be made between conditions in the absorbing material at a very early epoch and conditions today. Of considerable importance in this regard is the coincidence between the optical and radio redshifts and the implications that the terrestrial physical laws are valid throughout most of spacetime (Tubbs and Wolfe 1980).

A search for absorption features in the radio continuum of PKS 1157+014 was initiated at Arecibo. The search was successful, and in 1980 May we detected a redshifted 21 cm absorption feature near 482.5 MHz.

II. OBSERVATIONAL RESULTS

Our search for the absorption line was carried out with the 305 m antenna of the National Astronomy and Ionosphere Center located near Arecibo, Puerto Rico. A portion of the 305 m diameter surface was illuminated by the same 40 foot (12 m) phase-correcting line feed used previously to detect the 512 MHz absorption line in the

QSO MC3 1331+170 (Wolfe and Davis 1979). The feed was retuned to the expected frequency $\nu_d = 1420.405752 (1 + z_d)^{-1} = 482.5$ MHz by mouting it in a position 3 feet (91 cm) lower than that of the previous study. This resulted in an antenna sensitivity of ~ 8 K/Jy for zenith angles below 12°. The receiving system incorporated the University of Pittsburgh liquid-nitrogen cooled GaAs FET[1] preamplifier. The FET preamplifier was kindly provided by the University of California Radio Astronomy Laboratory at Berkeley and has a noise temperature of ~ 20 K. Unfortunately, the noise temperature of the assembled system includes contributions of ~ 30 K from line feed losses, ~ 20 K from an isolator placed between the feed and preamplifier, and ~ 25 K from the sky background. Thus the system temperature near zenith is 95 K. Since PKS 1157+014 is observed at high zenith angles at Arecibo, spillover from the ground adds an additional 20 K to the noise temperature and simultaneously inflicts ~ 30% reduction in antenna gain. Nonetheless, the final system had a noise temperature equivalent to the antenna temperature of a 20 Jy source at Arecibo.

The observations were made in a total power mode that alternated between integrations of 5 min on source and 5 min in an off-source reference region. We chose a 5 MHz bandwidth that was centered on 482 MHz (thereby placing potential 21 cm features from any of the other redshift systems outside our passband) and analyzed it with the 1008-channel autocorrelation spectrometer to obtain spectra with a channel spacing of 4.8828 kHz. The actual resolution after a single Hanning smoothing is nearly 9.8 kHz corresponding to a velocity resolution of 6 km s^{-1}.

[1] Field Effect Transistor.

The first observation was made on 1980 May 11. An absorption feature was detected at the expected location of ν_d after 25 min of on-source integration. On 1980 May 12 observations were conducted with the University of Pittsburgh uncooled parametric amplifier, and from 1980 May 13–16 we again used the cooled GaAs FET receiver. On the final 3 days we switched to a 2.5 MHz bandwidth to place some strong interference near 479.5 MHz outside the passband of the spectrometer. In all, we obtained 135 min of useful on-source integration time. Some editing of the data was necessary to remove interference and scans with baseline ripple. Apparently, there were low-level reflections in the IF cables (which are seldom used for spectral-line observations since these cables carry signals from low-frequency receivers) that produced waves across the passband with period ~ 750 kHz. During times of rapid temperature variability, these waves vary slightly between the on-source and off-source integrations and therefore are incompletely subtracted during the differencing stage of data reduction. Despite the editing, it is probably these waves which limit the precision of the measurement, rather than the stochastic receiver noise.

Figure 1*a* shows the final spectrum after subtraction of a polynomial baseline. In Figure 1*b* the same spectrum has been smoothed over 10 channels (i.e., 30 km s^{-1}) to maximize the signal-to-noise ratio: a 7 σ feature is clearly present at the frequency predicted by the optical redshift z_d.

The reality of the absorption feature is verified by several independent tests:

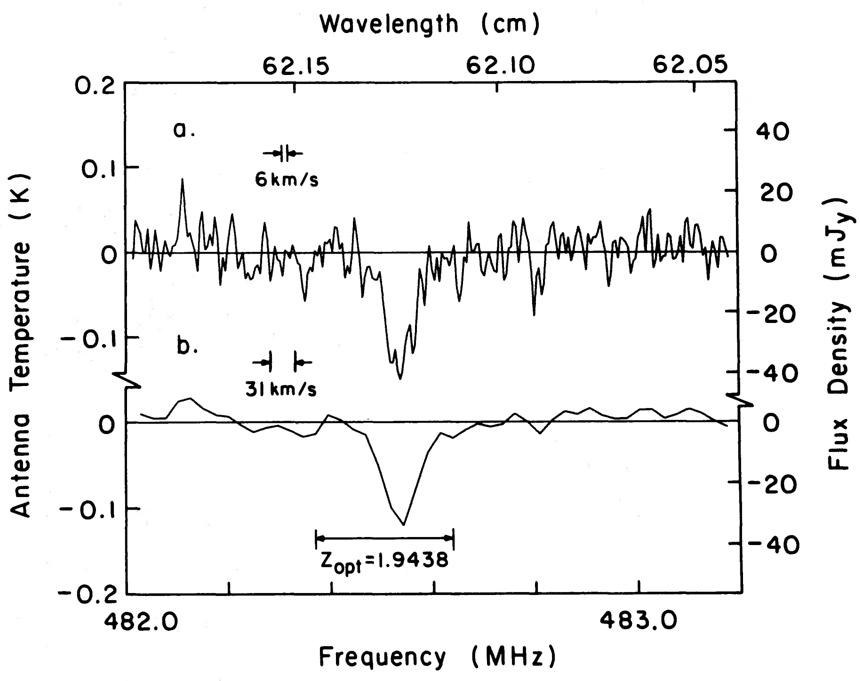

FIG. 1.—The observed radio spectrum of PKS 1157+014 near 482.5 MHz. (*a*) 6 km s^{-1} resolution, (*b*) 31 km s^{-1} resolution

1. *The feature does not arise from sporadic interference.* Inspection of daily averages as well as individual 5 min ON-OFF spectra shows that the feature is always present at the proper strength within the limitations of the signal-to-noise ratio. Moreover, inspection of individual ON and OFF spectra shows that the feature appears as an absorption dip in the ON and not as a spurious emission rise in the OFF. We note that interference occurring weakly in the OFF would have to be synchronized with our ON-OFF sequences, whose timing was virtually random from day-to-day.

2. *The feature is not due to a frequency-dependence of the gain across the passband of the receiving system.* On 1980 May 15 and 16 we observed the radio sources PKS 1055+01 and PKS 1330+02 in the same total power mode as PKS 1157+01. Both sources have declinations similar to 1157, but bracket it in right ascension. In addition, both are brighter than 1157 at 482.5 MHz. An imperfection in the passband should be reproduced with a strength proportional to the continuum flux density of the source. Figure 2 shows the raw spectra from the two-day average of data for 1157, and for an equivalent integration time for the summed spectrum of PKS 1055+01 plus PKS 1330+02. The absorption feature is present only in the observations of 1157 (both spectra do show a gradient of 3% in system gain across the region of the spectrum that we have plotted).

3. *The absorption feature re-appears with a sidereal period.* Due to the daily advance of solar time relative to sidereal time, observations of PKS 1330+02 on 1980 May 15 and 16 overlapped in GMT with observations of 1157 on 1980 May 11–14. Thus if feature *d* were caused by terrestrial interference, which somehow satisfied test (1), the source of interference must modulate with a sidereal period. We can think of no device, including sidereal clocks at the observatory, which operates in this manner.

We conclude that the 482.5 MHz feature is a true extraterrestrial absorption feature that arises in the spectrum of PKS 1157+01.

Although future observations with higher signal-to-noise ratios may reveal complex velocity structure on scales of ~ 5 km s^{-1}, we have fitted the line profile in Figure 1 with a single Gaussian function in order to deduce properties of the 21 cm absorber. The Gaussian is characterized by a velocity dispersion, $\sigma = 17.9 \pm 1.3$ km s^{-1}, which corresponds to a FWHM, $\Delta v = 42 \pm 3$ km s^{-1}. The frequency centroid is given by 482.537 ± 0.002 MHz, which is equivalent to a 21 cm redshift of $z_{21} = 1.94362 \pm 0.00001$ (heliocentric). This should be compared with the optical redshift of $z_{\rm opt} = 1.9438 \pm 0.0008$ (Wright *et al.* 1979.) The location of a 21 cm line predicted by the optical redshift is shown along with associated error bars in Figure 1*a*. The depth of the Gaussian function is given by $\Delta T_a = -0.135 \pm 0.009$ K. The 21 cm optical depth

$$\tau = -\ln\,[1 + (1/x)(\Delta T_a/T_a)]\,,$$

where T_a is the antenna temperature of the source, and x is the fraction of source flux (here measured by T_a) incident on the absorber along the line of sight. Normally one obtains T_a from drift scans or by driving the antenna beam across the source. However, during the course of our observations we discovered errors in telescope pointing which caused an effective loss in gain by the factor of about 0.7. Under these circumstances, a more realistic value of T_a for comparison with the spectral line observations is obtained from the difference in total power measured during on-source and off-source scans: this leads to $T_a = 2.80 \pm 0.03$ K where the uncertainty is derived from the scatter of the daily means.

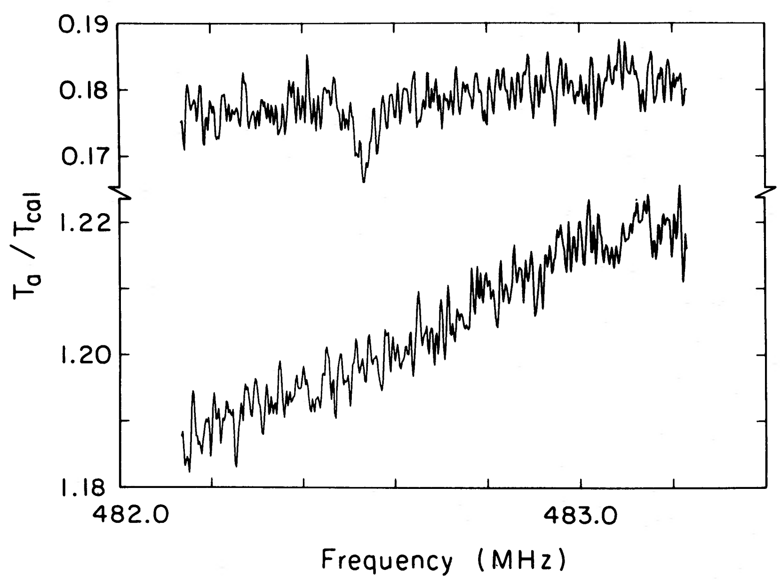

FIG. 2.—(*a*) Raw total power spectrum of PKS 1157+014 for the average of data taken in May; (*b*) raw total power spectrum for an integration time equal to that for (*a*) from combined data for 1055+01 and 1330+02. Since these sources are both much brighter than 1157+014, the gradient in system gain across the band is more apparent in (*b*).

As a result we find that the column density of neutral hydrogen implied by the 21 cm absorption feature is

$$N(\text{H I}) = 4.0 \times 10^{18} T_s \cdot C(x) \text{ cm}^{-2} ,$$
$$C(x) = \ln [1 + (1/x)(\Delta T_a/T_a)]/(0.049) ,$$
$$\Delta T_a/T_a = -0.048 . \quad (1)$$

The function $C(x)$ equals 1 when $x = 1$ and is given by $1/x$ for x in the range $\sim 0.25 \rightarrow 1$.

III. INTERPRETATION

We now turn to the physical implications of detecting a 21 cm absorption line at the optically predicted redshift z_d.

a) The Spin Temperature

The detection of Lyα and 21 cm absorption at the same redshift allows a determination of the spin temperature. This is possible because the absorption properties of Lyα lines produced by gas detected in 21 cm absorption are uniquely determined by N(H I) (cf. Wolfe 1979). By combining this quantity with deductions about the source structure used to determine $C(x)$ we can determine T_s using equation (1).

We feel certain that the wings of the Lyα absorption trough centered at $\lambda \approx 3580$ Å (cf. Wright *et al.* 1979) arise from absorption by a radiatively damped profile in system *d*, rather than from absorption by system *a* ($z_a = 1.9881$), *b* ($z_b = 1.9800$), *c* ($z_c = 1.9686$), or *e* ($z_e = 1.9207$) whose Lyα lines also fall within the trough. Constraints provided principally by the C IV and Si IV absorption lines show that the latter systems cannot produce the observed wings. Most important for our interpretation is the failure of system *e* to account for the blue wing. In order to mimic the gradual rise in intensity out of the trough, system *e* would have to contain gas with velocities of ~ 4000 km s^{-1} shortward of the Lyα line center for this system ($\lambda_e = 3551$ Å). The C IV line has a width (FWHM) of only ~ 800 km s^{-1}, thereby falling short by a factor of 10 in velocity spread. System *a* lies in the red wing, where it gives rise to a weak, unresolved Lyα feature at $\lambda_a = 3633$ Å. System *b* has narrow Si IV lines ($\sigma \lesssim 50$ km s^{-1}) and cannot contribute to the longward wing. In the case of system *c*, one could fit the longward wing of the trough with a profile having a half-width of ~ 2000 km s^{-1}. But this is about 5 times that required to fit the Si IV lines in this system.

These arguments would break down if Lyα absorption, and Si IV and C IV absorption, occurred in separate regions. In this case one could imagine separate zones with different velocity spreads. However, the absence of ions like C II, Si II, and Fe II in systems *a*, *b*, *c*, and *e* means that these systems do not contain H I regions. Lyα absorption will thus occur in the same ionized gas that gives rise to the N V, Si IV, and C IV lines. Therefore these redshift systems contribute negligibly to the total value of N(H I). For this reason and because the Lyα trough is centered on z_d we believe that the wings of the trough are due to the radiative damping profile of system *d*.

In order to determine N(H I) in system *d* we used an IDS spectrogram of 1157, kindly obtained for us by Junkkarinen and Burbidge (1979) at Lick Observatory, rather than the IPCS data of Wright *et al.* (1979) which is unreliable for studying features broader than 50 Å. Although the resolution and signal-to-noise of the IDS data are inferior to that of the IPCS spectrogram, the obvious continuity of the continuum level across the 3580 Å feature makes the IDS spectrogram ideally suited for fitting profiles over large wavelength intervals. We were unable to fit damping profiles centered at $\lambda_d = 3580$ Å to *both* wings of the absorption trough for any value of N(H I). This is because the longward wing shows a steeper increase away from the line center than does the shortward wing (the same asymmetry is also present in the IPCS spectrum). We believe that the steeper rise longward is due to the presence of a broad Lyα feature from the emission-line region, with a predicted central wavelength of $\lambda_{\text{em}} = 3620$ Å. Apparently the Lyα absorption of system *d* is broad enough to attentuate this emission below the continuum level at λ_{em}, but not at $\lambda \approx 3650$ Å where a sharp rise *above* the continuum is noticeable in the IDS spectrum: this latter feature merits further study, since Wright *et al.* (1979) state that no Lyα emission is present in this QSO. In any case, we obtained good agreement between the uncontaminated shortward wing and the theoretical profile when $N(\text{H I}) = (6.3 \pm 1.0) \times 10^{21}$ cm^{-2}. With this column density the predicted profile on the longward side of the line center agrees with the observed profile only if there is substantial Lyα emission by the QSO—further evidence that the QSO may not be abnormal in this respect.

The spin temperature derived by combining the 21 cm and Lyα data is given by

$$T_s = [1580/C(x)] \text{ K} . \quad (2)$$

Since $C(x)$ is a function of x, its value depends on the spatial structure of the 483 MHz radio source and on the origin of the absorption-line region. The radio spectrum suggests that the source consists of two components: an optically thin component with spectral index $\alpha = 1.0$ [where $\alpha = -d(\log S_\nu)/d(\log \nu)$] and an optically thick component with $\alpha = 0.3$ (see Fig. 3). We estimate that the thick component radiates less than 30% of the total flux density at 483 MHz (cf. Fig. 3). The angular diameter of the thick component is given by

$$\frac{\theta}{\text{milli-arcsec}} = 0.06\left(\frac{S_\nu}{1 \text{ Jy}}\right)^{1/2}\left(\frac{\lambda}{\text{cm}}\right)(1 + z_e)^{1/2}\left(\frac{10^{12} \text{ K}}{T_b}\right)^{1/2} , \quad (3)$$

where T_b is the brightness temperature at λ (O'Dell 1979). To obey the Compton limit, T_b must be less than 10^{12} K in the rest frame of the source; values inferred from VLB measurements are typically a few times 10^{11} K. Therefore the angular diameter of the optically thick component would be about 4 milli-arcsec, which corresponds to a linear diameter of ~ 40 pc. The optically thin component, however, could be larger than ~ 100 kpc.

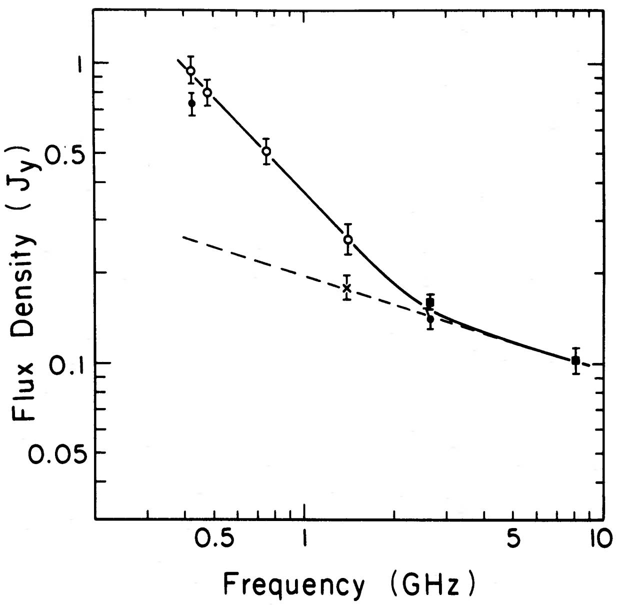

FIG. 3.—The spectrum of the radio continuum of PKS 1157+014. Open circles are our measurements made on the following dates: 427 MHz, 1978 Nov. 10; 485 MHz, 1980 May 10–16; 760 MHz, 1978 Nov. 11; 1400 MHz, 1979 Aug. 2. Filled circles are the data of Balonek *et al.* (1975). Filled squares are the data of Condon, Balonek, and Jauncey (1976). The cross represents 1400 MHz correlated flux density measured by ourselves with a VLB interferometer between Arecibo and Green Bank on 1979 Aug. 2.

The diameter of the absorber is unknown, but it might be any of a range of sizes depending on whether it is situated in a foreground galaxy or in a condensation of gas flowing out of the QSO. In the latter case, the size of the absorber is model-dependent (cf. Dyson, Falle, and Perry 1979), but it is unlikely to be less than N(H I)/n(H I), where n(H I) is the H I volume density. A study of the C II fine-structure level populations discussed below shows that in general n(H I) will not exceed $\sim 10^2$ cm^{-3} (cf. Fig. 4). As a result the size of the absorber will be $\gtrsim 20$ pc. Thus, the absorber should cover part or all of the compact component, since compact radio sources coincide with the optical continuum sources which presumably drive the outflow of gas. An ejected absorber may also overlap part of the extended component, but cannot cover enough of this low-surface-brightness source to produce an observable absorption feature. Consequently, in this case, we expect the 21 cm flux density incident on system d along the line of sight to be less than or equal to that emitted by the compact component, and so $x < 0.3$. For this reason, we have

$$\text{Outflow model: } T_s < 470 \text{ K} . \quad (4)$$

On the other hand, if system d is a foreground galaxy, the size of the absorbing region could be anywhere between ~ 1 and 30 kpc. The absorbing gas should cover the entire compact source and perhaps an appreciable fraction of the extended source as well. In this case we have

$$\text{Galaxy model: } 1/C(\gamma) < (T_s/1580 \text{ K}) < 1 , \quad (5)$$

where γ is the fringe visibility of the 483 MHz source detected with a VLB interferometer having a sufficiently long baseline to resolve out the extended component.

b) *The Location of Ststem d*

Let us assume that system d is located R(kpc) from the quasi-stellar radio source PKS 1157+01. If R is small enough, 21 cm continuum radiation competes with collisions in determining the hyperfine level populations,

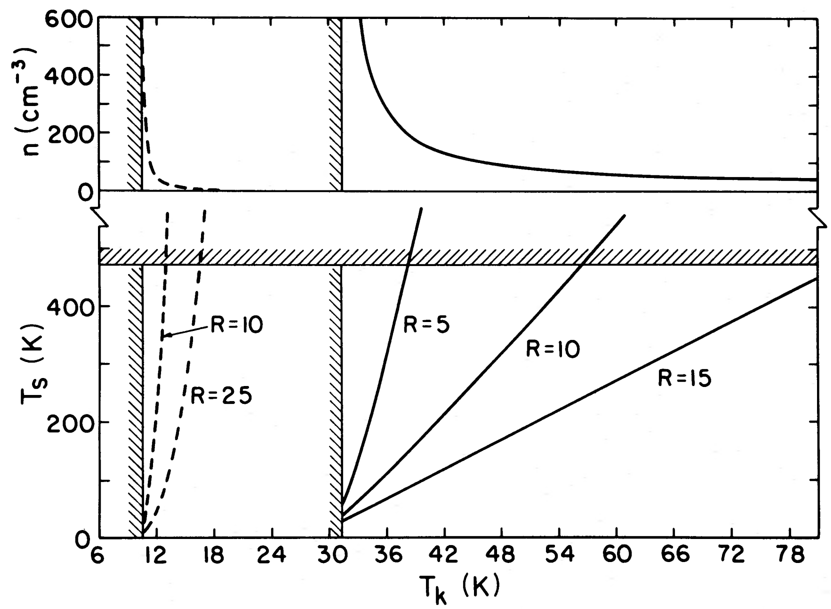

FIG. 4.—Density and spin temperature of system d when it is R kpc from 1157+01 and has a fractional ionization $n_e/n_H = 0.03$. The level populations n_u/n_l of the C II fine-structure states are used to obtain $n(T_k)$, and are combined with the 21 cm flux density at R to derive $T_s(T_k)$. Solid and dotted curves correspond to the cases $n_u/n_l = 0.1$ and 3×10^{-4}, respectively. The horizontal line with hatching represents the empirical limit $T_s < 470$ K, while the vertical lines with hatching represent the lower limits on T_k discussed in text (Wolfe and Wills 1977; Wolfe and Davis 1979).

causing T_s to significantly exceed the kinetic temperature T_k. In principle, the distance at which this occurs can be made arbitrarily small by raising the ambient density n so that the collision rate is arbitrarily large. However, the detection of λ1334.5 and λ1335.7 absorption lines which arise from the zero-volt $^2P_{1/2}$ and excited $^2P_{3/2}$ levels in C II, specifies n; otherwise collisions result in a ratio of level populations, $n_u(J = \frac{3}{2})/n_l(J = \frac{1}{2})$, that exceeds the empirical upper limit set by the ratio of equivalent widths $W_\lambda(13335.7)/W_\lambda(1334.5) = 0.42$. This in turn limits the rate at which collisions can thermalize the hydrogen hyperfine levels. Our observational constraints of $T_s < 470$ K therefore results in lower limits on R (cf. Wolfe and Davis 1979).

We have computed spin temperatures for various combinations of the free parameters T_k, R, and f (the fractional ionization of hydrogen) by adopting the ratio $n_u(J = \frac{3}{2})/n_l(J = \frac{1}{2}) = 0.1$. This ratio is conservative, because C II λ1344.5 is undoubtedly saturated: had we inferred n_u/n_l from a curve of growth constructed with the 21 cm velocity distribution, we would find that $n_u/n_l = 3 \times 10^{-4}$. The spin-temperature curves in Figure 4 indicate that $R > 10$ kpc. At smaller distances T_s increases so rapidly with T_k that T_k is restricted to temperatures that are implausibly low. Thus when $R = 10$ kpc, T_k is restricted to 31 K $< T_k <$ 56 K. As R decreases, the temperature range likewise decreases, and at $R = 5$ kpc we have 31 K $< T_k <$ 38 K. Figure 4 also illustrates the case $n_u/n_l = 3 \times 10^{-4}$ where T_k must lie between 10 K and 16 K when $R = 25$ kpc. In each case the lower limit is the minimum kinetic temperature for which a Boltzmann population of fine-structure levels equals the assumed n_u/n_l, while the upper limit is set by the condition $T_s(T_k) = 470$ K. The increase in T_s with T_k is due to the rapid decrease in n with T_k [$n \propto \exp\,(+92\ \mathrm{K}/T_k)$] dictated by the steady-state condition for fine-structure level populations, and the fact that T_s is proportional to n^{-1}. The value $f = 0.03$ used in our computations typifies the fractional ionization of the interstellar gas in our Galaxy. It is probably larger in a cloud situated near a QSO that emits a huge flux of (ionizing) keV X-rays, and yet has a density not much larger than that of interstellar matter (see Fig. 4). If f is larger than 0.03, the lower limit on R will also be larger, since the permitted range of T_k contracts with increasing f. We emphasize that these results are based on densities associated with the region producing C II absorption. That they also apply to the region producing 21 cm absorption follows from the good agreement between the curve of growth constructed with the Gaussian fit to the 21 cm velocity distribution and the pattern of equivalent widths of absorption lines arising in H I–like ions, such as Mg II, Fe II, C II, etc. This is in contrast with every other 21 cm redshift system, where such curves of growth are not compatible (cf. Wolfe 1980).

The problem with placing an ejected cloud at such large values of R is that the maximum photon momentum absorbed by system d as it accelerates to a distance R,

$$p_{\mathrm{rad}} = (L/c)(\Omega/4\pi)[2R/v(R)]\ ,$$

is considerably less than that inferred from observation,

$$p_{\mathrm{obs}} = m_{\mathrm{H}} N(\mathrm{H\ I}) R^2 \Omega v(R)\ .$$

Here Ω is the solid angle subtended by the absorber at the optical continuum source, L is the luminosity of the QSO, and $v(R)$ is the outflow velocity at R. In the present case

$$p_{\mathrm{rads}}/p_{\mathrm{obs}} = 10^{-2}(10\ \mathrm{kpc}/R)\ .$$

It is difficult to see how 1157 can drive system d to the required momentum if R is greater than ~ 1 kpc, unless there is an additional source of radial force.

The outflow picture is confronted with a similar paradox in the case of the 21 cm absorber in the QSO 1331+170; i.e., system A (Wolfe and Davis 1979). But in that case the spin temperature will not be affected by 21 cm continuum radiation. The reason is that Lyman continuum (Lc) photons emitted by the QSO convert to Lyman alpha (Lyα) photons in the ionized portion of the absorber. Then the Lyα photons propagate far inside the H I region where they determine the hyperfine level populations (Urbaniak and Wolfe 1981); recoil during the scattering process causes T_s to equal T_k (Field 1959). To see whether the same process operates in system d, we note that Lyα competes with 21 cm continuum excitations in a cloud with Lyα optical depth τ_α when $J_0(\tau_\alpha/2)$, the central mean intensity of Lyα at the midpoint, exceeds some critical value J_0(CRIT). Substituting the appropriate values of σ, N(H I), and the radio and optical flux densities into equation (35) of Urbaniak and Wolfe (1981), we find that $J_0(\tau_\alpha/2)/J_0(\mathrm{CRITT}) \approx 10\epsilon$, where ϵ is the efficiency of converting Lc to Lyα radiation (we have made use of the fact that the upper limit $v = 35\ \mathrm{km\ s^{-1}}$ on possible velocity separations between the H II and H I regions of system d places the input radiation within the Doppler core of the H I region, thereby limiting its penetration into the H I region [cf. Urbaniak and Wolfe 1981]). However, the large Lyα optical depth and velocity dispersion of system d indicate that $J_0(\tau_\alpha/2)/J_0(\mathrm{CRIT})$ will be smaller than our expression indicates, since in the limit of small v this was obtained from numerical calculations applied specifically to system A in 1331+170 where τ_α and σ are smaller; in our judgment 3ϵ is a more realistic estimate.

Therefore it appears that Lyα mixing can determine the spin temperature in system d, implying that R may be well below 10 kpc. However, if the ionization rates deduced from the optical data are taken into consideration, one finds that R is unlikely to be less than 10 kpc. More specifically, the upper limit on the ratio of N V to C IV equivalent widths indicates a small value for the ionization parameter y. When combined with our estimates of n_e, deduced from the C II fine-structure data, this results in lower limits on R, since $y \propto F$ (ionizing)/n_e and the ionizing flux is specified; we find that $R > 15$ kpc. In principle, R could be much smaller, if the absence of N V were due to attenuation of the ionizing flux by any one of the other absorption systems. But this would also result in far too little Lyα radiation generated for Lyα mixing to keep $T_s \approx T_k$, and the 21 cm continuum would then drive

T_s well above the observed limits. For these reasons we believe that 10 kpc is safe lower limit on R.

Therefore, while we cannot definitely exclude the possibility that system d is accelerated by the QSO, the sum of all the evidence suggests that it is not.

c) *Uniformity of Physical Constants*

The coincidence of radio and optical redshifts in system d means that variations of the product of physical constants $\alpha^2 g_p m/M$ between the spacetime location of the absorption event and here and now is given by

$$|\Delta \ln (\alpha^2 g_p m/M)| = |(z_{\rm opt} - z_{21})/(1 + z_{21})| . \quad (6)$$

Here α is the fine-structure constant, g_p is the gyromagnetic ratio of the proton, and m/M is the ratio of electron-to-proton mass. This quantity is restricted by the accuracy to which $z_{\rm opt}$ is determined. We find that $|\Delta \ln (\alpha^2 g_p m/M| \leq 2.7 \times 10^{-4}$. The significance of this result is that it represents the sixth spacetime event (including us, now) for which uniformity of physical constants has been established. Moreover, the large comoving separation between the 21 cm absorption events in PKS 11157+01 and AO 0235+16 (Roberts *et al.* 1976) requires that the particle horizons of these events intersect in a region comprising less than 25% of the volume encompassed by the particle horizon of the absorption event in AO 0235+16. Stated differently, the physical constants at both events are the same even though 75% of the matter that is casually connected to the absorber in AO 0235+16 is causally disconnected from the absorber in PKS 1157+01. Tubbs and Wolfe (1980) showed that the 21 cm absorption events in AO 0235+16 and MC3 1331+17 were also causally disjoint, and concluded that this was evidence for uniformity of physical laws throughout most of spacetime. That argument is reinforced by the present case since the particle horizon of the 0235+16 event intersects less material (~ 10% less) from the horizon of the 1157+01 event from the 1331+17 event.

IV. DISCUSSION

We have detected a 21 cm absorption line in the radio continuum of PKS 1157+014 with a redshift $z = 1.94362$. This is the largest redshift yet reported at radio frequencies, and represents the second redshifted 21 cm line successfully predicted by properties of Lyα absorption spectra; i.e., a large ratio of Lyα to metal absorption equivalent widths (cf. Wolfe 1980).

An important piece of information obtained from our detection is the upper limit on the spin temperature. When combined with other limits on hyperfine excitation, this implies the distance limit of $R > 10$ kpc separating absorber from QSO. While not as large as distance limits derived from the optical data alone (cf. McKee, Tarter, and Weisheit 1973), the limits on R inferred from the spin temperature are at least partially free of the ambiguities attending the optical techniques. That is, the absence of N V absorption in addition to the C II fine-structure data imply that the flux of ionizing radiation incident on system d is small compared to the fluxes incident on the other absorbing clouds. The flux at cloud d could be small because of geometrical dilution in which case $R > 15$ kpc, or because it is attenuated by passage through other absorption systems in which case $R \ll 10$ kpc is permissible. However, we have shown that the presence of 21 cm absorption rules out the latter possibility. The attenuation of ionizing radiation also results in insufficient Lyα production for Lyα mixing to keep $T_s = T_k$. As a result the 21 cm continuum will drive T_s above the observed limit when $R < 10$ kpc. In the absence of attenuation, the derived limit on distance is $R > 15$ kpc, which makes radiative ejection of system d from the QSO difficult to understand.

For these reasons we believe that the difference between the emission-line redshift of PKS 1157+01 and the absorption-line redshift in system d originates either in the Hubble expansion, in which case $R \sim 10$ Mpc, or from peculiar velocities in a rich cluster of galaxies, in which case R could be somewhat smaller. Either explanation is possible, but we prefer the cluster hypothesis because 10 Mpc is close to cluster dimensions, and because the velocity between the QSO and system d, $v = 4360$ km s^{-1}, lies within the range of the "cluster" velocity distribution inferred by Weymann *et al.* (1979) from their survey of a complete sample of QSO absorption-line systems.

We note that the kinematics and density structure of system d are not inconsistent with the galaxy hypothesis. The line of sight to 1157 would have to intercept a rather edge-on (inclination angle $i < 10°$), late-type spiral to traverse the few kpc of the H I disk required to account for the large H I column density, and to account for the 40 km s^{-1} extent of the absorption profile. Furthermore, the ionization state of system d resembles that of our own Galaxy is that N V absorption is also absent in *IUE* spectra of the galactic corona (Savage and de Boer 1979); indeed, the presence of strong N V absorption in the remaining redshift systems in 1157 supports the view that this gas *does* originate in an outflow from the QSO. The similarity between the equivalent width ratio of C II (λ1335.7)/C II (λ1334.5) in system d and in our Galaxy (de Boer and Savage 1980) suggests an additional resemblance of excitation conditions. However, the analogy is made dubious by the possibility that the background star or H II region contaminates the C II fine-structure population of supposed interstellar gas (Spitzer and Jenkins 1975). The only evidence that might contradict the galaxy hypothesis is lack of dust. With a column density N(H I) $= 6.3 \times 10^{21}$ cm^{-2} we would expect that $E(B-V) \approx 1.3$ mag and that the dust optical depth due to the 2200 Å feature would be about 12. The absence of any strong absorption near $\lambda = (1 + z_d)$ (2200) = 6476 Å implies that the dust-to-gas ratio in system d is at least 10 times less than is normally found in our Galaxy. Jura (1977) found a similar result for the 21 cm absorber in MC3 1331+170. Therefore, if these high-z H I regions are disks of foreground galaxies, the cycling of interstellar gas through repetitive processes of stellar evolution must result in normal element abundances by $t \sim 5 \times 10^9$ yr, with little, if any, condensation of gas into grains like those in our Galaxy.

The outcome of this experiment was largely dependent on the successful operation of a low-noise GaAs FET preamplifier. We take pleasure in acknowledging the generosity of Jack Welch, director of the Berkeley Radio Astronomy group, for placing at our disposal the expertise and facilities needed to construct low-frequency GaAs FET preamps. We owe an equal debt of thanks to Tap Lum, director of the electronics laboratory at Berkeley, for guiding us in the art of GaAs FET preamp construction, and for supplying us with the preamplifier actually used in this experiment. We also thank George Gull of Cornell University for building us a liquid-nitrogen Dewar, and Jose Cruz, Ernesto Ruiz, and Angel Vazquez of the Arecibo staff for their capable assistance in acquiring the data. We are grateful to R. J. Weymann for providing valuable comments. A.M.W. and F.H.B. are supported by NSF grant AST 79-07760.

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