THE ASTROPHYSICAL JOURNAL, 414:500–505, 1993 September 10


# NEUTRAL HYDROGEN ABSORPTION AND EMISSION IN THE QUASAR/GALAXY PAIR 3C 275.1/NGC 4651

STEPHEN E. SCHNEIDER
Five College Astronomy Department, and Department of Physics and Astronomy, University of Massachusetts, 632 Lederle Tower, Amherst, MA 01003

AND

EDVIGE CORBELLI
Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, 50125 Firenze, Italy
*Received 1992 December 10; accepted 1993 March 3*

## ABSTRACT

3C 275.1 and NGC 4651 make a particularly interesting quasar/galaxy pairing because of the alignment of such a strong radio emitter behind the outer H I disk of a relatively undisturbed spiral galaxy. This provides an opportunity to study the spin-temperature characteristics of atomic hydrogen at low column densities, in an apparently star-free environment. We previously reported a tentative detection of absorption against the quasar based on VLA C-array observations; we have now made more sensitive maps of the H I emission from NGC 4651 with the VLA D-array, and we have attempted to confirm the weak H I absorption against the quasar at higher spatial and spectral resolution in VLA B-array. The possible absorption feature against this quasar appears to be weaker than we previously suspected, even though it seems fairly clear that H I emission is present close to the line of sight to the quasar. The weakness of the possible absorption seems also to confirm the trend found in previous observations that where strong absorption lines are seen, the galaxies show evidence of disturbance. The possible detection of (or limits on) absorption suggest that the neutral gas in the outer disk is quite warm. We use the absorption and emission measurements to set lower limits on the combination of heating inputs outside the star-forming regions of a disk galaxy and/or the intensity of the cosmic background radiation around 100 eV.

*Subject headings:* galaxies: individual (NGC 4651) — quasars: individual (3C 275.1) — radio lines: galaxies

## 1. INTRODUCTION

Absorption systems at low redshift are particularly interesting because of the possibility of examining a galaxy's gaseous component in emission as well as absorption, unlike the much more numerous cases of absorption identified at high redshift. However, due to the varying identification techniques applied at different redshifts, it is not entirely clear how to relate the evolution and type of absorbing systems seen at different epochs (Wolfe 1990; Blades 1988; Morton, York, & Jenkins 1986). The absorption systems normally attributed to galaxies at intermediate redshifts are usually associated with the redshifted Mg II line, whereas at low redshifts the optical Ca II line is usually used to identify an absorption system and this requires a higher total column density of gas. In almost all cases at low redshifts where Ca II absorption lines have been found, the absorption line is broad and the foreground galaxy shows evidence of merging or tidal disturbance (Carilli & van Gorkom 1992; Bowen et al. 1991). This may be just a selection effect that results from the fact that it is only in such systems that high H I column density gas is thrown out to large galactocentric distances.

Absorption lines arising clearly from undisturbed outer disks or halos of low-redshift galaxies have not been identified. Today's normal disk galaxies might be the final product of high-redshift systems which have shrunk or have lost most of their outer regions during evolution (Charlton & Salpeter 1989). In this case some faint gas might have been left in the halo or in the disk several tens of kiloparsecs beyond their optical radius and might be detectable through the 21 cm line of neutral hydrogen.

The ability to detect 21 cm lines in absorption generally requires a relatively high column density of gas, comparable to the inner disk column densities required to detect Ca II absorption. However, if the spin temperature of H I is as low as 100 K, then 21 cm absorption can be detected also for $N_{\rm H\,I} \sim 10^{19}$ cm$^{-2}$. This is why in Paper I (Corbelli & Schneider 1990) we approached the problem of the gas in outer regions by searching for 21 cm absorption against radio sources which lay along lines of sight passing close to galaxies. Cataloged radio sources of adequate brightness were sufficiently numerous that we could examine a relatively large sample of 59 radio background sources at angular separations of up to seven optical radii from cataloged galaxies. We searched for 21 cm absorption using the Arecibo radio telescope. Therefore, our survey was primarily sensitive to the sort of narrow-line absorption that might be expected from undisturbed gas because we could not easily eliminate the possibility of broad features being masked by sidelobe emission within the beam or by bandpass irregularities. In the end, we found no clear-cut cases of absorption, except for one suspected very weak feature which is the subject of this paper.

The lack of a significant presence of cold H I over a wide range of radii outside of the optical dimensions of spiral galaxies leaves us with three possibilities: (i) the faint gas extends far out but it is mostly warm; (ii) there is a sharp transition between H I and H II beyond a critical column density; or (iii) the gas is sharply truncated after a certain radius. Accurate constraints on the spin temperature and very sensitive emission searches would help in deciding which of these three alternatives generally applies. If case (i) or (ii) are correct, the data would give important information on the soft X-ray background or on other possible heating mechanisms outside the star-forming region of disk galaxies. In two recent papers, Corbelli & Salpeter (1993a, b) have in fact shown how one could use spin temperature and sensitive emission searches to constrain the cosmic background below 500 eV.

We have therefore investigated further the one "suspicious" feature we had found in Paper I using the VLA.[1]

The preliminary results in Paper I were based on a relatively short integration in the VLA C-array, which showed a possible 21 cm absorption in the 3C 275.1/NGC 4651 pair. However, neither that observation nor earlier ones made at Westerbork by Warmels (1988) were sufficiently sensitive to detect H I emission as far out as the position of 3C 275.1. H I had been detected only for $N_{\rm H\,I} \geq 10^{20}$ cm$^{-2}$, while in some previously studied cases 21 cm absorption had been found at lower column densities (Carilli & van Gorkom 1992). To further study the H I emission in NGC 4651, we therefore observed the galaxy in VLA D-array, which gives us a higher sensitivity to lower column densities of H I than our earlier C-array observations.

In contrast to the other low-redshift cases of 21 cm absorption, where Ca II absorption was also found, NGC 4651 shows a regular H I disk and no clear evidence of companions. Thus the presence of such a strong radio source near NGC 4651 presents a unique opportunity to study the properties of gas in the outer disk of a relatively undisturbed disk by its 21 cm H I absorption. NGC 4651 has sometimes been regarded as peculiar or disturbed because of a faint "jet" (Sandage, Véron, & Wyndham 1965) extending from the galaxy. In Figure 1, we show this morphology with a *B*-band image of NGC 4651 obtained at the NOAO Kitt Peak 0.9 m telescope. Figure 1*a* shows that the central high surface brightness regions of NGC 4651 look like a fairly normal Sc galaxy, while the "stretch" in panel (*b*) emphasizes the peculiar linear feature dubbed a jet. The linear feature is clearly inconsistent with any traditional notion of a jet since it neither points back at the nucleus of the galaxy nor is it projected along the minor axis of the galaxy nor does it produce detectable radio continuum emission. The morphology of the feature is also difficult to match to a tidal stream given its straightness right up to the immediate proximity of the galaxy, where it makes a sharp angle with respect to the outer spiral arms. Moreover, there is no indication of a disturbance in the H I emission associated with the feature (Warmels 1988; this paper); therefore it seems more likely to be a foreground or background feature seen in projection, or some sort of dynamical feature—perhaps similar to the Magellanic Stream seen edge-on—which is far enough beyond the galaxy's disk that it causes no obvious disturbance. This is a very curious feature, but it does not seem to play any role in the current investigation.

Because of the weakness of the possible absorption detected with C-array we also reobserved the galaxy in B-array, which

[1] The Very Large Array is a facility of the National Radio Astronomy Observatory operated by Associated Universities, Inc., under contract with the National Science Foundation.

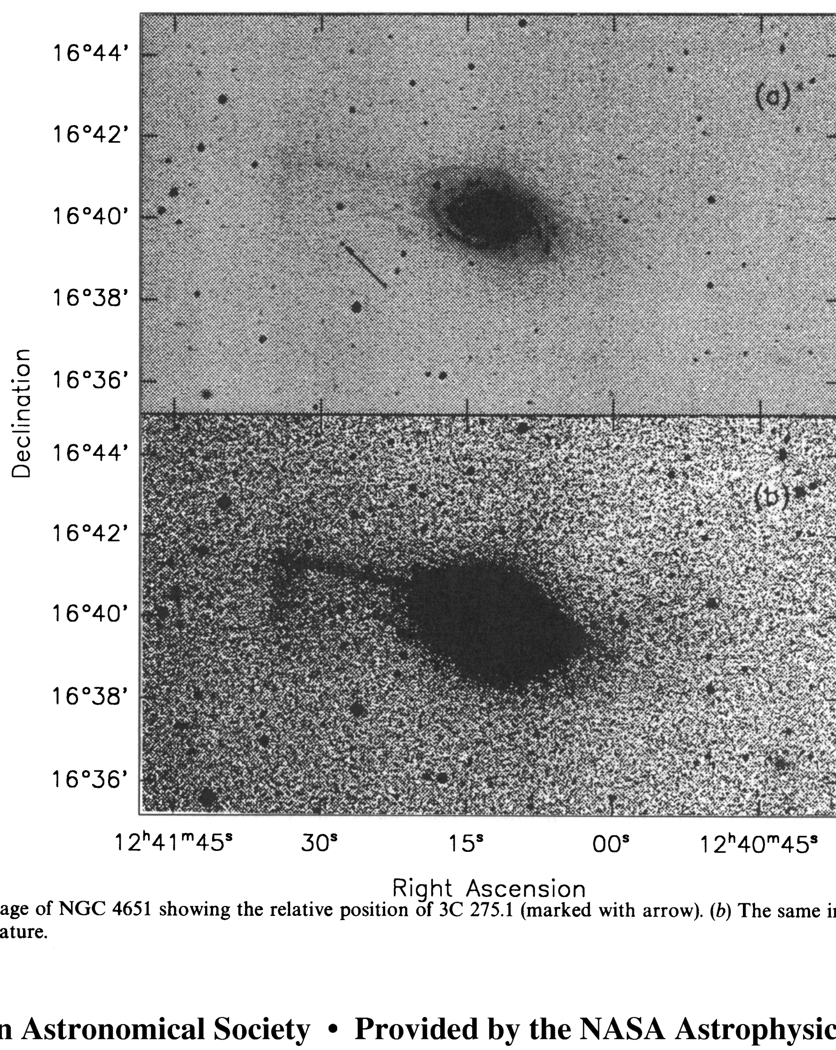


FIG. 1.—(*a*) *B*-band image of NGC 4651 showing the relative position of 3C 275.1 (marked with arrow). (*b*) The same image "stretched" to bring out the low surface brightness linear feature.

allowed us to use both higher spatial and spectral resolutions than before. The higher spatial resolution of the B-array gave us a much better match to the actual angular size of the two principal emission components of the quasar, each of which has a flux density greater than 1 Jy, and these observations had the further advantage of spatially "filtering out" almost all of the H I emission (because of the lack of short *u-v* spacings). The results of the B-array observations suggest that the H I absorption is weaker than we previously suspected, if it is present at all, even though the new D-array observations now give us better evidence that H I emission is present at the positions surrounding that of the quasar. Despite the uncertainties on the presence of a weak 21 cm absorption line, the combination of new emission and absorption measurements we present in this paper leads to some interesting conclusions on the conditions of the gas outside the optical disk of NGC 4651, and it has implications for the heating inputs in outer regions of quite normal and undisturbed galaxies.

In § 2 we present specifics of the absorption and emission observations and the data reduction performed at the VLA. We discuss first the original C-array observations, and then in turn the B-array observations made to examine the absorption, and the D-array observations of the galaxy's emission. In § 3 we attempt to interpret the observations, specifically attempting to reconcile the differences between B- and C-array. Finally, in § 4 we summarize our results and discuss the implications of these measurements for the spin temperature of neutral hydrogen in the outer disks galaxies.

## 2. VLA OBSERVATIONS OF H I IN 3C 275.1/NGC 4651

Three sets of 21 cm spectral line observations were made at the VLA, in the B-, C-, and D-arrays giving approximately 6", 22", and 60" resolution, respectively. Various resolutions were necessary because of the ranges of angular sizes involved: NGC 4651 has an angular diameter of about 5', while the quasar 3C 275.1 consists of two primary components a few arcsec in diameter. The C-array observations were made 1989 August 4 as part of a survey of three possible quasar/galaxy absorption systems identified in Paper I, and follow-up B-array observations of the absorption were made 1990 August 4. Observations of the H I emission were made 1991 March 26 in D-array. We also attempted absorption measurements in D-array (using observing parameters identical to those for the B-array observations), but confusion with H I emission from the galaxy prevented any definitive interpretation of the results; we do not discuss these observations further.

In this section and in the next one we describe the reductions and results of each set of observations, deferring a comprehensive discussion of the results to § 4.

### 2.1. *VLA C-Array:* H I *Absorption*

The C-array observations were centered on the position of 3C 275.1 and at the velocity of 700 km s$^{-1}$ which is close to where absorption was suspected based on our earlier Arecibo spectrum. The integration consisted of two 35 minute blocks of time, separated by $\sim$3 hr to improve *u-v* coverage. Twenty-seven antennas and two polarizations were used. On-line Hanning smoothing with 128 spectral channels over a 1.56 MHz bandpass yielded a velocity resolution of $\sim$2.6 km s$^{-1}$. Standard amplitude, phase, and bandpass calibration were performed using primary VLA calibrator 3C 286, which was fortuitously only about 18° away. The synthesized beam had a full-width at half-maximum of $\sim$22".

Because of limitations on the total bandpass versus number of channels available, only velocities spanning the low-velocity half of H I emission from the galaxy were observed. We produced a continuum map from the average of the first and last several spectral channels for the purpose of removing continuum emission from the individual channels, but since the last channels were not line free, the subtraction was not ideal. A small residual at the position of the H I with a velocity near $\sim$800 km s$^{-1}$ resulted, but the effect of this on the continuum-subtracted maps was minor since the H I emission was quite weak and several arcminutes removed from the position of the quasar. Essentially identical results were obtained after using only the channels from the line-free end of the spectrum, or when we performed subtraction of the continuum emission in the *u-v* plane.

The integrated flux density from 3C 275.1 was measured to be 2.96 Jy based on channels from the line-free end of the spectrum, which is in good agreement with our measurement at Arecibo (Paper I). H I in NGC 4651 could be seen in emission at velocities near 640 km s$^{-1}$ in the vicinity of the quasar. We looked at the spectrum of each pixel at position of the quasar and we noticed a dip near this velocity. In Figure 2 we plot part of the spectrum integrated over a 18" × 18" region centered on the quasar. (Note that this spectrum appears slightly different from the preliminary one published in Paper I due to small changes in the reduction method and a simpler pixel-weighting scheme.) A second-order polynomial fit was subtracted from the spectrum shown. A maximum apparent optical depth of 0.0067 ± 0.0012 is found at $v_{\rm hel} = 643$ km s$^{-1}$ based on a formal analysis of the mean and rms away from the dip. A second broader but weaker feature is also marginally visible at 636 km s$^{-1}$, with a formal depth of 0.0033 ± 0.0014. Spectra were also made using different *u-v* weighting, different

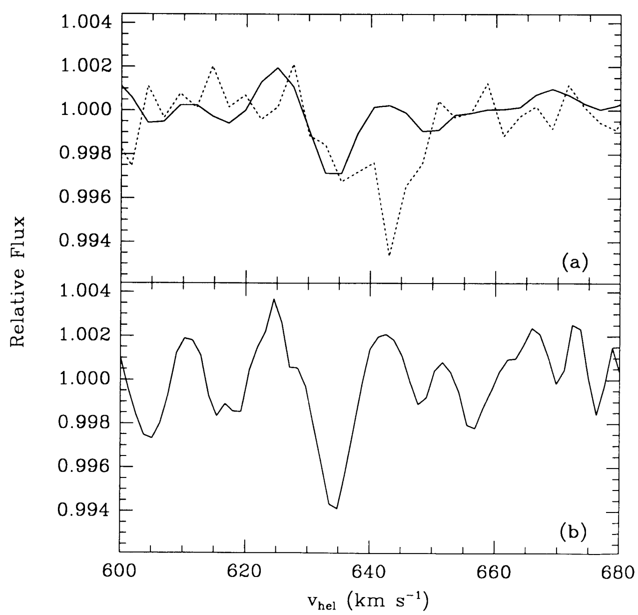


FIG. 2.—(*a*) Absorption spectrum against the entire quasar 3C 275.1 as found in the C-array (*dashed line*) and B-array (*solid line*). The B-array data has been smoothed both spatially and in frequency resolution to match the C-array. The vertical scale is displayed relative to the total flux density over the pixels sampled. (*b*) Possible absorption feature found in B-array data as measured near the center of 3C 275.1.

levels of cleaning, and from different halves of the recorded data, all giving consistent dips near 640 km s$^{-1}$. No significant variations in the bandpass calibration at this velocity appeared to be present.

### 2.2. *VLA B-Array:* H I *Absorption?*

A year later, we reobserved this system with spatial and frequency resolutions better optimized to study the characteristics of the suspected absorption. The quasar contains two radio-bright lobes (1.1 and 1.4 Jy to the north and south respectively) and a fainter (0.2 Jy) central source according to a high-resolution map of Stocke, Burns, & Christiansen (1985). The lobe sources are separated by 15″, and they are each several arcsec across. The central source is unresolved.

The B-array resolution of 6″ was a good match to the size of the two strong continuum sources, and it offered the possibility of distinguishing between absorption characteristics at the two positions. The observations were again centered on 3C 275.1 at a heliocentric velocity of 640 km s$^{-1}$. The integration time was spread over a 10 hr observing run, with an actual integration time of ~7 hr on source after accounting for calibration and slewing. Amplitude, phase, and bandpass calibration were again performed using 3C 286. Twenty-seven antennas and two polarizations were used. On-line Hanning smoothing with 64 spectral channels over a 0.39 MHz bandpass (~80 km s$^{-1}$) yielded a velocity resolution of ~1.3 km s$^{-1}$. The synthesized beam had a full-width at half-maximum of ~6″.

No H I emission was apparent in our channel maps, presumably because of the combination of poorer surface-brightness sensitivity in the B-array, and the loss of short *u-v* spacings, but 3C 275.1 was clearly resolved into its northern and southern (combined with the central) components with measured flux densities of approximately 0.9 and 1.9 Jy, respectively. The integrated flux density measured from 3C 275.1 was 2.94 Jy, in excellent agreement with the C-array results.

When smoothed to the resolution of the C-array (both spatially, and in frequency), the B-array results show much weaker evidence of H I absorption (Fig. 2). The feature at 643 km s$^{-1}$ has almost completely disappeared, leaving only a weak possible absorption line at 636 km s$^{-1}$. Somewhat better evidence of absorption (Fig. 2) at 636 km s$^{-1}$ was found in the full resolution B-array data at the position corresponding to the central source as mapped by Stocke et al. (1985). The spectrum showed a slight curvature (of a few tenths of a percent) so that a second-order polynomial fit was subtracted from the spectrum shown in Figure 2; this did not significantly affect the estimates of optical depth. The peak optical depth was $0.0059 \pm 0.0016$, and the integrated optical depth was $\int \tau\, dv = 0.030$ km s$^{-1}$. Only a very slight suggestion of absorption at the 643 km s$^{-1}$ velocity was found when examining points aligned with the northern component of 3C 275.1.

### 2.3. *VLA D-Array:* H I *Emission from NGC 4651*

Additional observations of NGC 4651 were made to map out its H I emission properties. D-array observations provide better H I surface density sensitivity, but there is also a more difficult problem in determining the emission at a particular point because of the larger beam size.

The observations were centered on NGC 4651 at its systemic heliocentric velocity of 800 km s$^{-1}$. Approximately 6 hr of integration time for the emission measurement was spread over a 10 hr observing run. Amplitude, phase, and bandpass calibration were again performed using 3C 286. Twenty-seven antennas and two polarizations were used. On-line Hanning smoothing with 64 spectral channels over a 3.125 MHz bandpass (~650 km s$^{-1}$) yielded a velocity resolution of ~10 km s$^{-1}$.

The line-free channels to either side of the velocity range of the galaxy were averaged and subtracted from the remaining channels, and the resulting channel maps had a typical noise per beam of about 1 mJy. The four times longer integration, and the lower velocity and spatial resolutions of these maps made them about 20 times more sensitive to extended emission than the original C-array observations, with a limiting sensitivity (3 $\sigma$) of about $10^{19}$ cm$^{-2}$. The integrated flux density of 3C 275.1 was measured at 2.70 Jy.

The integrated emission maps and flux-weighted mean velocity maps are shown in Figure 3. Overall, the emission is fairly symmetric and the velocity field is quite regular. Around the position of 3C 275.1, the maps become somewhat irregular because of small uncertainties in the bandpass correction which leave significant residuals when such a strong continuum source is subtracted from the individual channel maps. Several different methods (including *u-v* line subtraction and *u-v* source subtraction) were also attempted, but they all produced equivalent results. No indication of the optical "jet" is apparent in these maps.

The amount of H I emission at the position of 3C 275.1 was estimated from a spectrum taken through the 20 pixels (the beam area was 18.6 pixels in our image) centered at the posi-

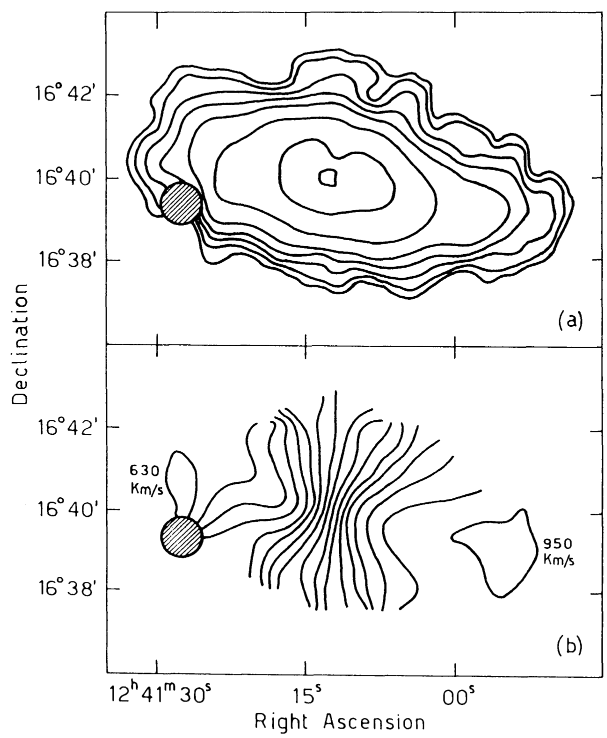


FIG. 3.—(*a*) Contours of integrated H I emission in NGC 4651 at column densities corresponding to approximately 1.5, 3, 8, 15, 30, 80, 150, and 240 × $10^{19}$ cm$^{-2}$. The data were taken in D-array with an effective beam size of 62″ × 59″. The beam size is shown as a cross-hatched region centered on the position of the quasar. (*b*) Isovelocity contours of the H I, based on the flux-weighted mean, at intervals of 20 km s$^{-1}$. The lowest contour, at left-hand-side of the figure, is for 630 km s$^{-1}$, the highest one is 950 km s$^{-1}$ at the opposite side of the figure.

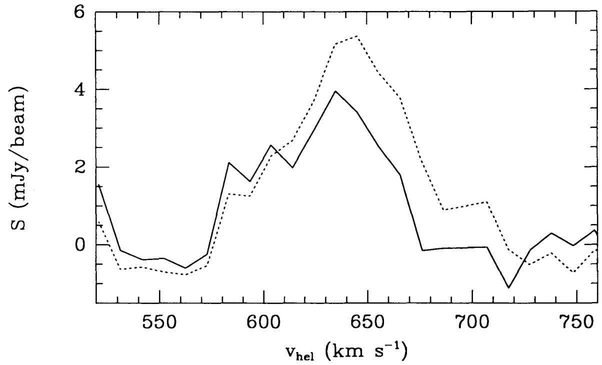


FIG. 4.—H I spectrum at the position of the quasar in D-array. The solid line shows a baseline-subtracted spectrum in the direction of 3C 275.1; the dashed line shows the spectrum from an annulus surrounding the quasar.

tion of the quasar in the CLEANed image (Clark 1980). Because of the difficulties in removing such a strong source, a second-order baseline had to be fitted and subtracted in order to estimate the line flux at the position of the quasar. The resulting spectrum (Figure 4) peaks at approximately 634 km s$^{-1}$ in agreement with the velocity of the possible absorption found in the B-array observations. To check that the baseline subtraction was reasonable, we also measured the H I spectrum in a narrow annulus surrounding the quasar. Here the baseline was linear, and the resultant spectrum is in good agreement. The integrated flux over the line is 0.23 Jy km s$^{-1}$ per beam in this measurement, corresponding to an average column density of H I over the beam of $7.4 \times 10^{19}$ cm$^{-2}$.

A column density measured with a beam this large represents only the average amount of gas that might be in front of the quasar. If the gas is clumpy, there may be more or less H I along the particular line of sight to the quasar. Fortunately, the quasar is fairly extended, so it should more nearly sample the average properties of the gas. However, a systematic effect arises because of the exponential gradient of H I across the beam, which tends to bias the measurement toward the higher values of the column density at the edge of the beam. We estimate the correction to our measurement by modeling the H I as having an exponential decline with a scale length $s$, and the beam as being a Gaussian with a half-power beam width $\theta = (8 \ln 2)^{1/2} a$, where $a$ is the standard deviation of the Gaussian. The measured flux is based on the product of the beam and exponential decline:

$$\int \exp(-x^2/2a^2) \exp(-x/s)\, dr$$

$$= \int \exp[-(x + a^2/s)^2/2a^2] \exp(a^2/s^2)\, dr$$

$$= \sqrt{2\pi}\, a \exp(a^2/s^2) ,$$

which is a factor of $\exp(a^2/s^2)$ greater than the actual flux at that position. Note that we can treat this as an essentially one-dimensional problem because the beam is small compared to the curvature in isodensity contours at the position of the measurement. By measuring the falloff at corresponding positions in the other three quadrants of the galaxy, we estimate the scale length of the H I at the position angle of the quasar as $s \approx 30''$. For the beam width of $\theta = 60''$, the flux would be overestimated by factor of $\sim$2.1. Thus the column density of H I is better estimated at $\sim 3.5 \times 10^{19}$ cm$^{-2}$ at the position of the quasar.

## 3. INTERPRETATION OF THE OBSERVATIONS

It is well known that detecting weak spectral features in the presence of strong continuum sources is difficult (see van Gorkom & Ekers 1989; Cornwell, Uson, & Haddad 1992, for a discussion of this problem), but despite repeated attempts and different methods of analysis, we can find no clear explanation for the significantly stronger absorption we find with our C-array observations. The most disturbing element of these observations is that the earlier C-array feature was at least nominally better than $\sim 5\ \sigma$, while at the same velocity the B-array shows no feature. There does appear to be a lower velocity absorption line which might be consistent in both B- and C-arrays, but the feature is weak ($\tau_{max} \lesssim 0.006$), is limited to regions near the center of 3C 275.1, and is uncomfortably near our detection limit.

The differences between B- and C-array results could have been caused by imperfect sidelobe subtraction of the H I emission. This can occur when negative sidelobes from H I emission very near to the quasar in a particular channel are imperfectly subtracted. Yet after applying various taperings in the $u$-$v$ plane, and a variety of "cleaning" techniques, we cannot confirm this speculation.

For the variation to be real would require some improbable circumstances. Motion transverse to the line of sight due either to rotation or to turbulence in the disk of NGC 4651 is extremely unlikely to proceed rapidly enough to cause the sorts of large changes we see. Briggs (1988) has pointed out that a variable background source may cause a shift in the position of the absorption line. Since the overall fluxes measured with B- and C-array are in very good agreement, we might suppose that the quasar has ejected a "blob" while maintaining the same total flux, so that different lines of sight in NGC 4651 are effectively sampled. However, for the case we are examining this explanation is effectively ruled out by the following argument: (i) most of the flux comes from the north and south lobes and not from the central source which should be the source of such rapid motion; and (ii) 3C 275.1 is at a redshift $\sim$150 times greater than NGC 4651, so that even assuming superluminal motion for the blob in the quasar of $v \sim 10\, c$ the opacity in the medium of NGC 4651 would have to change dramatically over scales $\ll 1$ pc to explain the observed variations in the absorption profiles.

For the time being, we attribute the apparently strong absorption at 643 km s$^{-1}$ to a random deviation in our C-array data. This explanation is not entirely satisfactory, but until better data are obtained, it seems a more reasonable alternative than invoking a change in the geometry of the background source. The weaker feature at 636 km s$^{-1}$ appears to be consistent in both the B- and C-array observations and the peak corresponds closely to the velocity of the emission maximum as determined from the *D*-array observations. However, its weakness (it is a quarter as strong as the feature in the C-array observation at 643 km s$^{-1}$) precludes any definitive conclusion and in the following section we will treat it as an upper limit.

## 4. DISCUSSION

Although some uncertainties remain about the strength of absorption in the 3C 275.1/NGC 4651 pair, it now appears fairly clear that H I emission is present along the line of sight to the quasar from the outer disk of NGC 4651 at the level of $N_{HI} \sim 3 \times 10^{19}$ cm$^{-2}$. The gas in this outer region appears to be relatively undisturbed, making this alignment especially interesting for studies of the physical characteristics of disk gas outside the stellar disk. This should be contrasted with the majority of other large-separation quasar/galaxy absorption systems where the 21 cm absorption appears to be related to tidal features. The weakness of the absorption in this system is consistent with the idea that 21 cm absorption as well as Ca II or Na I absorption outside the optical disk are found prevalently in disturbed systems which are richer in metals and have a higher neutral column density of gas. However, even in this type of system it seems very likely that if there is some cold gas, which absorbs the 21 cm radiation, this is mixed with warmer gas. It would be quite informative to explore Ca II or Na I absorption against 3C 275.1, but unfortunately its optical counterpart is quite faint: $m_v = 19.0$ (Burbidge et al. 1971). Extrapolating from observations like those of Bowen et al. (1991), detection of the optical lines would require very lengthy integrations. *HST* observations of the UV absorption spectrum might be a better alternative if 3C 275.1 is sufficiently bright at shorter wavelengths.

Independently of whether there is an absorption line in the spectrum of 3C 275.1 caused by gas associated with NGC 4651, we can use the weakness of the absorption as a probe of possible heating inputs in the outer regions of this low-redshift spiral galaxy. Assuming the deeper feature observed with C-array is a "glitch" in the spectrum, and treating the apparent absorption at 636 km s$^{-1}$ as either a detection or an upper limit to the optical depth, we have

$$T_S = 5.14 \times 10^{-19} \frac{N_{\rm H\,I}}{\int \tau\, dv} \gtrsim 500 \text{ K} ,$$

where we use the column density from our D-array observations and the integrated optical depth in front of the quasar from our B-array data. We note again that all absorption/emission measurements suffer from the possibility that the gas could be clumpy. Thus the particular column density along the line of sight to the quasar could be higher or lower than the mean value represented by the emission in the surrounding regions.

Applying a correction factor for the inclination of the galaxy with respect to our line of sight, we find the H I surface density in NGC 4651 at the location of the quasar: $\sigma_{\rm H\,I} \sim 2 \times 10^{19}$ cm$^{-2}$. Corbelli & Salpeter (1992a) have shown that such H I surface densities in outer regions have spin temperatures $T_S >$ 500 K only if the heat per atom deposited by some mechanism is larger than $10^{-15}$ eV s$^{-1}$ (the exact value depends upon the gas volume density). If this heating is provided by a cosmic flux described by the power law $I \times E^{-2.4}$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$ down to 100 eV, then $I > 10$. This result, based on half of solar metallicity, does not depend much on the metallicity since in order to have these large values of $T_S$ the medium should be in the warm phase with the cooling dominated by H-*e* impact. The heating requirements do not change much even if it is only one part of the gas which is cold and absorbs the radiation. Given a total H I surface density of the gas $\sim 2 \times 10^{19}$ cm$^{-2}$, Corbelli & Salpeter (1992a, Fig. 5) show in fact that a warm phase at $T_S > 500$ K can coexist with a cold one only if $I > 10$. A two-phase medium would have been also the most logical conclusion derived from the stronger feature previously thought to be present in the C-array data (due to its small width and small optical depth).

These limits on the background flux around 100 eV are sufficiently low that they have a direct bearing on the level of a QSO-dominated background. Madau (1992) estimated an intensity only 2 times lower than our limit for a perfectly transparent intergalactic medium. Due to possible rms deviations and sidelobe contamination in the emission and absorption spectra of 3C 275.1/NGC 4651 we cannot exclude that such background is the only heating source for the gas. A stronger background, as recently suggested by new estimates of the bright QSO space density, would give gas spin temperatures in even closer agreement with our estimates. We would, however, exclude much weaker cosmic backgrounds unless additional sources of energy are present in the outer regions of normal spirals. This conclusion is also supported by the consistency between the values or lower limits for $T_S$ derived in this paper for the outer disk of NGC 4651, and the lower limit of 250 K found for $T_S$ in the outer disk of M33 (Paper I) for similar values of the H I surface density.

Although some doubts remain about weak features in outer regions, our study is consistent with the conjecture that strong absorption lines at low redshifts arise mainly in disturbed systems. At the same time, because tidal features often have stars associated with them and relatively high column densities of H I, they are poorer probes of the soft X-ray background. Even though the absorption features may be weak and difficult to detect, we believe further studies of H I emission and absorption in outer reaches of undisturbed galaxies hold great promise for exploring the energetic environments of galaxies.

We would like to thank E. Salpeter for a number of helpful discussions during the preparation of this paper, J. Spitzak for helping to obtain the B-band image of NGC 4651, and the referee for comments on the original manuscript. This work was supported in part by a PYI award from the NSF (AST 91-58096) and the Agenzia Spaziale Italiana. S. E. S. also thanks the Arcetri Observatory for their hospitality and support while visiting.

## REFERENCES

Blades, J. C. 1988, in QSO Absorption Lines, ed. J. C. Blades et al. (Cambridge: Cambridge Univ. Press), 147
Bowen, D. V., Pettini, M., Penston, M. V., & Blades, J. C. 1991, MNRAS, 249, 145
Briggs, F. H. 1988, in QSO Absorption Lines, ed. J. C. Blades et al. (Cambridge: Cambridge Univ. Press), 275
Burbidge, E. M., Burbidge, G. R., Solomon, P. M., & Strittmatter, P. A. 1971, ApJ, 170, 233
Carilli, C. L., & van Gorkom, J. H. 1992, ApJ, 399, 373
Charlton, J. C., & Salpeter, E. E. 1989, ApJ, 346, 101
Clark, B. G. 1980, A&A, 89, 377
Corbelli, E., & Salpeter, E. E. 1993a, ApJ, submitted
Corbelli, E., & Salpeter, E. E. 1993b, ApJ, submitted
Corbelli, E., & Schneider, S. E. 1990, ApJ, 356, 14 (Paper I)
Cornwell, T. J., Uson, J. M., & Haddad, N. 1992, A&A, 258, 583
Madau, P. 1992, ApJ, 389, L1
Morton, D. C., York, D. G., & Jenkins, E. B. 1986, ApJ, 302, 272
Sandage, A. R., Véron, P., & Wyndham, J. 1965, ApJ, 142, 1307
Stocke, J. T., Burns, J. O., & Christiansen, W. A. 1985, ApJ, 299, 799
van Gorkom, J. H., & Ekers, R. D. 1989, in Synthesis Imaging in Radio Astronomy, ed. R. A. Perley et al. (Green Bank: NRAO), 341
Warmels, R. H. 1988, A&AS, 72, 427
Wolfe, A. M. 1990, in The Interstellar Medium in Galaxies, ed. H. A. Thronson & J. M. Shull (Dordrecht: Kluwer), 387